A

SYSTEM

OF

CHEMISTRY.

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A SYSTEM OF CHEMISTRY.

IN FOUR VOLUMES.

BY THOMAS THOMSON, M.D.

LECTURER ON CHEMISTRY IN EDINBURGH.

THE SECOND EDITION.

VOL. I.

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1804.

TO

JOHN BARCLAY, M.D.

LECTURER ON ANATOMY.

SIR,

THE motives which induced me to prefix your name to the first Edition of this Work, still continue to operate with undiminished force. Your general knowledge, your particular views, and the intimate connection between Chemistry and that science of which you are so great a master, qualify you in a peculiar manner to judge of the merits of a Work which you originally suggested, and which you will receive as a pledge of that intimate friendship which we have so long enjoyed. I am,

DEAR SIR,

Your sincere Friend,

And humble Servant,

THE AUTHOR.

EDINBURGH,
Feb. 1. 1804.

PREFACE.

THE general attention which is at present paid to Chemistry in Britain cannot escape the most superficial observer. The sale of a large Edition of a Work so extensive as the present, in less than ten months after its publication, is a decisive proof that the votaries of the science are numerous and daily increasing. Indeed it possesses such attractive charms, and sheds so beneficial an influence over the arts and manufactures, that to be welcomed and cultivated it requires only to be known. And if we consider the number of eminent chemists at present in the British Empire, we cannot but indulge the most flattering hopes of the future progress of the science. Some years ago it was affirmed in a continental journal, and a chemist of eminence attached his name to the assertion, that Britain possessed scarcely a scientific chemist. The remark was prefixed to an account of a set of experiments on a subject of importance. In this account many interesting facts and observations are stated as new, though they had been almost all anticipated three years before by Dr Wollaston. The experiments of the British chemist must have been unknown to the continental philosopher, as he observes with regard to them the most profound silence ; yet they had appeared in the Philosophical Transactions, the most celebrated work in England or even in Europe.

At present it is not likely that any man, how partial so ever to his own circle or his own country, would hazard the ridicule of such an assertion. We can reckon the names of not a few philosophers still worthy of the Country of Bacon and of Newton, where Philosophical Chemistry first originated; who cultivate the science with assiduity and success; and who have already enriched it with the most important discoveries. Nor is it meant to depreciate the illustrious Chemists on the Continent; the science has been deeply indebted to their genius, and still requires their fostering care. Indeed so important, so difficult, so vast, so infinite, are the objects of Chemistry, that it can only be rapidly and successfully improved by the united exertions of all nations, tongues, and languages.

The object of this Work was to facilitate, as much as possible, the progress of Chemistry, by collecting into one body the numerous facts which lay scattered through a multiplicity of writings, by blending with them the history of their gradual developement, and by accompanying the whole with exact references to the original works in which the discoveries have been registered. The avidity with which the Work was received, and the private or public approbation of some of our most eminent Chemists, are flattering proofs that it was not considered as useless. A new Edition was demanded many months ago; but the Author was unwilling to lay it again before the Public without making it as worthy as possible of their acceptance. The slightest comparison of the present Edition with the former will be sufficient to shew how materially it has been altered. Almost two-thirds of the whole have been written anew: A great number of additional facts have been introduced, many of them original, either resulting from the experiments of the Author, or with which he has been favoured by some of our most celebrated Chemists. Every publication to which the Author had access has been ransacked; and no pains have been spared to render the Work as complete a transcript as possible of the present state of the science. But notwithstanding all his care, he is very far from wishing to insinuate that he has executed his task completely. Mistakes and omissions, the result of ignorance or inattention, will still claim the indulgence of the Reader. But it may be said, without any impropriety, that the present Edition contains a more complete collection of facts, and in a smaller compass, than any work of the kind which the Author has had an opportunity of examining.

It would be improper to pass over in silence the many observations on the former Edition with which the Author has been privately favoured, or which have made their appearance in the different Journals. To these the present Edition is much indebted for its accuracy. Several hundred errors, chiefly in the numerals, have been pointed out and corrected, which would have probably escaped the familiar eye of an Author. The observations on the plan, the arrangement, and the execution of the Work, have been carefully and impartially examined, the improvements suggested have been adopted, while the remarks which appeared inapplicable or unjust have been disregarded. Of the last class indeed the Author has had but seldom reason to complain; most of his critics having treated him with the most liberal indulgence. One solitary instance only of uncandid severity has occurred.

Notwithstanding the objections which have been made to the plan, the Author, after mature consideration, has still ventured to adhere to it without any essential alteration. Indeed it is but seldom that the hasty opinion of others concerning the plan of a work of science is to be put in competition with that of the original contriver. To criticise it with success requires a person who has the same turn of thinking, who possesses the same information, and who has bestowed upon the subject the same patient meditation as the Author himself. The two first requisites may be easily found; but, in most cases at least, neither the vanity nor impatience of reviewers admit of the third. All the critical observations regarding the plan of the present Work resolve themselves into two; namely, 1. That it contains too much; 2. That it contains too little. These opposite assertions, which refute and destroy one another, afforded the Author considerable satisfaction; as they suggested to him that in all probability he had not deviated very far from that happy middle path which every author of a system of this kind ought to follow.

The arrangement of a work is still more open to censure than its plan. Every man considers himself as qualified to judge in that department; and every man views with prejudice and dislike the most trifling deviation from that order to which he has been accustomed. Few consider that the art of arranging is one of the most difficult tasks of the philosopher; that it requires a comprehensiveness of mind, a clearness of judgment, and a patience of labour, which fall to the lot of a small number only of the human race. Few consider that no man, even though possessed of the mental qualifications, is capable of forming a proper judgment of an arrangement, unless he be thoroughly acquainted with all the substances classified, unless he have studied their mutual dependence, and carefully considered the method of communicating his knowledge to others. Nor is his opinion to be trusted even then, unless he have the candour to overlook the difference of situation and circumstances, and have no favourite child of his own to support and prefer with the blind partiality of a parent. Let the reader consider the objections thrown out against Linnæus, and he will acknowledge with a blush the truth of these remarks.

The arrangement adopted in the present Work differs indeed from that of others. To this objection, which has been so triumphantly urged, the Author pleads guilty. But it was not adopted without mature consideration, and a careful examination of every other chemical arrangement of which information could be procured. It has been attentively reviewed in no less than seven chemical courses, which the Author has now given; and has been gradually improved into its present state. If this Work possess any superiority over others, if it be more perspicuous or more complete, we must ascribe it to the arrangement. It is independent altogether of hypothesis, and as nearly inductive or analytical as was consistent with the state of the science; it presupposes no previous knowledge of the subject, and begins with those parts of the science which have been most successfully investigated, and which therefore admit of a plainer and simpler mode of illustration. This renders the science more accessible to beginners, smooths and removes many of the difficulties, and enables the Author to give a more entertaining and connected view of the subject than would otherwise have been possible. These reaſons alone would have entitled it to the preference; but others of still greater weight will doubtless occur to the practical chemist. The Author has the satisfaction of adding, that it has been examined and approved by several eminent philosophical friends, in whose judgment and skill he places the highest confidence.

It was intended at first to have terminated the fourth volume with some remarks upon the Chemical Nomenclature; but the great size to which that volume imperceptibly swelled, rendered the addition improper. The omission, however, is of small importance, and need not be regretted. The Author in most cases agrees with Mr Chenevix, in whose valuable remarks on the Chemical Nomenclature the Reader will find complete satisfaction. His improvements have been mostly adopted in this Work. The reasons for the few instances of deviation will probably suggest themselves on a little reflection; and if they should not, the differences are too trifling to merit much attention.

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Study of nature

As soon as man begins to think and to reason, the different objects which surround him on all sides naturally engage his attention. He cannot fail to be struck with their number, diversity, and beauty; and naturally feels a desire to be better acquainted with their properties and uses. If he reflect also, that he himself is altogether dependent upon these objects, not merely for his pleasures and comforts, but for his very existence, this desire must become irresistible. Hence that curiosity, that eager thirst for knowledge, which animates and distinguishes generous minds.

Divided into history and science.

Natural objects present themselves to our view in two different ways; for we may consider them, either as separate individuals, or as connected together and depending upon each other. In the first case, we contemplate Nature as in a state of rest, and consider objects merely as they resemble one another, or as they differ from one another: in the second, we examine the mutual action of substances on each other, and the changes produced by that action. The first of these views of objects is distinguished by the name of *Natural History;* the second, by that of *Science.*

Science

Natural science, then, is an account of the *events* which take place in the material world. But every event, or, which is the same thing, every change in bodies indicates motion; for we cannot conceive change, unless at the same time we suppose motion. Science, then, is in fact an account of the different *motions* to which bodies are subjected, in consequence of their mutual action on each other.

Of two kinds, viz.

Now bodies vary exceedingly in their distances from each other. Some, as the planets, are separated by many millions of miles; while others, as the particles of which water is composed, are so near each other, that we cannot, by our senses at least, perceive any distance between them; and only discover, by means of certain properties which they possess, that they are not in actual contact. But the *quantity* of change or of motion, produced by the mutual action of bodies on each other, must depend, in some measure at least, upon their distance from one another. If that distance be great enough to be perceived by the eye, and consequently to admit of accurate measurement, every change in it will also be perceptible, and consequently will admit of measurement. But when the distance between two bodies is too small to be perceptible by our senses, it is evident that no change in that distance can be perceptible; and consequently every relative motion in such bodies must be insensible.

Mechanical philosophy and chemistry

Science therefore naturally divides itself into two great branches: the first, comprehending all those natural events which are accompanied by *sensible* motions; the second all those which are not accompanied by *sen-*

sible motions. The first of these branches has been long distinguished in Britain by the name of *Natural Philosophy*, and of late by the more proper appellation of *Mechanical Philosophy;* the second is known by the name of *Chemistry*.

Definition of chemistry.

CHEMISTRY, then, is that science which treats of those events or changes in natural bodies which are *not* accompanied by *sensible* motions.

Its importance.

Chemical events are equally numerous, and fully as important, as those which belong to mechanical philosophy: for the science comprehends under it almost all the changes in natural objects with which we are more immediately connected, and in which we have the greatest interest. Chemistry therefore is highly worthy of our attention, not merely for its own sake, because it increases our knowledge, and gives us the noblest display of the wisdom and goodness of the Author of Nature; but because it adds to our resources, by extending our dominions over the material world, and is therefore calculated to promote our enjoyment and augment our power.

As a science, it is intimately connected with all the phenomena of nature; the causes of rain, snow, hail, dew, wind, earthquakes; even the changes of the seasons can never be explored with any chance of success while we are ignorant of chemistry: and the vegetation of plants, and some of the most important functions of animals, have received all their illustration from the same source. No study can give us more exalted ideas of the wisdom and goodness of the Great First Cause than this, which shews us everywhere the most astonishing effects produced by the most simple though adequate means, and displays to our view the great care which has everywhere been taken to secure the comfort and happiness of every living creature. As an art, it is intimately connected with all our manufactures: The glass-blower, the potter, the smith, and every other worker in metals, the tanner, the soapmaker, the dyer, the bleacher, are really practical chemists; and the most essential improvements have been introduced into all these arts by the progress which chemistry has made as a science. Agriculture can only be improved rationally, and certainly, by calling in the assistance of chemistry; and the advantages, which medicine has derived from the same source, are too obvious to be pointed out.

Origin.

The word CHEMISTRY seems to be of Egyptian origin, and to have been originally equivalent to our phrase *natural philosophy* in its most extensive sense, comprehending all the knowledge of natural objects which the ancients possessed. In process of time it seems to have acquired a more limited signification, and to have been confined to the *art of working metals* *. This gradual change was no doubt owing to the immense importance attached by the ancients to the art of working metals. The founders and improvers of it were considered as the greatest benefactors of the human race; statues and temples were consecrated to their honour; they were even raised above the level of humanity, and enrolled among the number of the gods.

How long the word *chemistry* retained this new signification, it is impossible to say; but in the third cen-

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* Our English word *physician* has undergone a similar change.

tury we find it used in a still more limited sense, signifying the art of *making gold and silver*. The cause of this new limitation, and the origin of the opinion that gold can be made by art, are equally unknown. Chemistry, in this new sense, appears to have been cultivated with considerable eagerness by the Grecian ecclesiastics, to have passed from the Greeks to the Arabians, and by the Arabians to have been brought into the west of Europe. Those, who professed it, gradually assumed the form of a sect, under the name of ALCHYMISTS; a term which is supposed to be merely the word *chemist*, with the Arabian article *al* prefixed.

The Alchymists.

The alchymists laid it down as a first principle, that all metals are composed of the same ingredients, or that the substances at least, which compose gold, exist in all metals, contaminated indeed with various impurities, but capable, by a proper purification, of being brought to a perfect state. The great object of their researches was to find out the means of producing this change, and consequently of converting the baser metals into gold. The substance which possessed this wonderful property they called *lapis philosophorum*, "the philosophers stone;" and many of them boasted that they were in possession of that grand instrument.

Their opinions,

Chemistry, as the term was used by the alchymists, signified the art of making the philosophers stone. They affirmed that this art was above the reach of the human capacity, and that it was made known by God to those happy sages only whom he peculiarly favoured. The fortunate few who were acquainted with the philosophers stone called themselves *adepti*, "adepts;" that is, persons who had got possession of the secret.

This secret they pretended they were not at liberty to reveal; affirming, that dire misfortune would fall upon that man's head who ventured to disclose it to any of the sons of men without the clearest tokens of the divine authority.

In consequence of these notions, the alchymists made it a rule to keep themselves as private as possible. They concealed, with the greatest care, their opinions, their knowledge, and their pursuits. In their communications with each other, they adopted a mystical and metaphorical language, and employed peculiar figures and signs, that their writings might be understood by the adepts only, and might be entirely unintelligible to common readers. Notwithstanding all these obstacles, a great number of alchymistical books made their appearance in the dark ages; many of them under the real names of the authors; but a still greater number under feigned titles, or ascribed to the celebrated sages of antiquity.

How far alchymy had extended among the ancients, or whether it had even assumed the form of a sect, cannot be ascertained. Traces of it appear among the Arabians, who turned their attention to literature soon after the conquests of the Caliphs, and who communicated to our barbarous ancestors the first seeds of science. The principal chemical writers among the Arabs were Geber and Avicenna; and in their writings, such of them at least as we have reason to consider as authentic, there appears but little of that mysticism and ænigma which afterwards assumed a systematic form.

The alchymists seem to have been established in the west of Europe as early at least as the 9th century. Between the 11th and 15th centuries, alchymy was in its most flourishing state. The writers who appeared during that period were sufficiently numerous, and very different from each other both in their style and abilities. Some of their books are altogether unintelligible, and bear a stronger resemblance to the reveries of madmen than to the sober investigations of philosophers. Others, if we make allowance for their metaphorical style, are written with comparative plainness, display considerable acuteness, and indicate a pretty extensive acquaintance with natural objects. They often reason with great accuracy, though generally from mistaken principles; and it is frequently easy enough to see the accuracy of their experiments, and even to trace the particular circumstance which led to their wrong conclusions.

The principal alchymists who flourished during the dark ages, and whose names deserve to be recorded, either on account of their discoveries, or of the influence which their writings and example had in determining the public taste, were Albertus Magnus, Roger Bacon, Arnoldus de Villa Nova, Raymond Lully, and the two Isaacs of Holland*.

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* Albertus Magnus was a German. He was born in the year 1205, and died in 1280. His works are numerous; but the most curious of them is his tract entitled *De Alchymia*, which contains a very distinct view of the state of chemistry in the 13th century.

Roger Bacon was born in the county of Somerset in England in 1224. His merit is too well known to require any panegyric. The greater number of his writings are exceedingly obscure, and even mystical; but he generally furnishes us with a key for their explanation. Some of them exhibit a wonderfully enlightened mind for the age in which he wrote. His tract *De mirabili potestate Artis et Naturæ* would have done honour to Lord Bacon himself.

And writings.

The writings of the greater number of alchymists are remarkable for nothing but obscurity and absurdity. They all boast that they are in possession of the philosophers stone; they all profess to communicate the method of making it; but their language is ænigmatical, that it may be understood by those adepts only who are favoured with illumination from heaven. Their writings, in those benighted ages of ignorance, gained implicit credit; and the covetous were filled with the ridiculous desire of enriching themselves by means of the discoveries which they pretended to communicate. This laid the unwary open to the tricks of a set of impostors, who went about the world affirming that they were in possession of the secret of the philosophers stone, and offering to communicate it to others for a suitable reward. Thus they contrived to get possession of a sum of money; and afterwards they either made off with their booty, or tired out the patience of their pupils by intolerably tedious, expensive, and ruinous processes. It was against these men that Erasmus directed his well-known satire, entitled, "The Alchymist." The tricks of these impostors gradually exasperated mankind against the whole fraternity of alchymists. Books appeared against them in all quar-

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Arnoldus de Villa Nova is believed to have been born in Provence, about the year 1240. His reputation was very high; but all of his writings that I have examined are exceedingly obscure, and often not intelligible.

Raymond Lully was born at Barcelona in 1235. His writings are still more obscure than those of Arnold. The most celebrated of them is his "Last Will and Testament," which has been translated into English.

It is not known at what period the Isaacs of Holland lived, though it is supposed to have been in the 13th century.

ters, which the art of printing, just invented, enabled the authors to spread with facility; the wits of the age directed against them the shafts of their ridicule; men of science endeavoured to point out the impracticability, or at least the infinite difficulty of the art; men of learning rendered it probable that it never had been understood; and men in authority endeavoured by laws and punishments to guard their subjects from the talons of alchymistical impostors.

Universal medicine.

Chemists had for many ages hinted at the importance of discovering a universal remedy, which should be capable of curing, and even of preventing all diseases; and several of them had asserted, that this remedy was to be found in the philosophers stone, which not only converted baser metals to gold, but possessed also the most sovereign virtue, was capable of curing all diseases in an instant, and even of prolonging life to an indefinite length, and of conferring on the adepts the gift of immortality on earth. This notion gradually gained ground; and the word *chemistry*, in consequence, at length acquired a more extensive signification, and implied not only the *art of making gold*, but the art also of *preparing the universal medicine* *.

Just about the time that the first of these branches was sinking into discredit, the second, and with it the study of chemistry, acquired an unparalleled degree of celebrity, and attracted the attention of all Europe.

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* The first man who formally applied chemistry to medicine was Basil Valentine, who is said to have been born in 1394, and to have been a Benedictine Monk at Erford in Germany. His *Currus triumphalis Antimonii* is the most famous of his treatises. In it he celebrates the virtues of antimonial medicines, of which he was the original discoverer.

This was owing to the appearance of Theophrastus Paracelsus. This extraordinary man, who was born in 1493, near Zurich in Switzerland, was, in the 34th year of his age, after a number of whimsical adventures, which had raised his reputation to a great height, appointed by the magistrates of Basil to deliver lectures in their city; and thus was the first public Professor of chemistry in Europe. In two years he quarrelled with the magistrates, and left the city; and after running through a complete career of absurdity and debauchery, died at Salzburg in the 47th year of his age.

The character of this extraordinary man is universally known. That he was an impostor, and boasted of secrets which he did not possess, cannot be denied; that he stole many opinions, and even facts, from others, is equally true: his arrogance was unsupportable, his bombast ridiculous, and his whole life a continued tissue of blunders and vice. At the same time, it must be acknowledged that his talents were great, and that his labours were not entirely useless. He contributed not a little to dethrone Galen and Avicenna, who at that time ruled over medicine with absolute power; and to restore Hippocrates and the patient observers of Nature to that chair, from which they ought never to have risen. He certainly gave chemistry an eclat which it did not before possess; and this must have induced many of those laborious men, who succeeded him, to turn their attention to the science. Nor ought we to forget that, by carrying his speculations concerning the philosophers stone, and the universal medicine, to the greatest height of absurdity, and by exemplifying their emptiness and uselesness in his own person, he undoubtedly contributed more than any man to their disgrace and subsequent banishment from the science.

Van Helmont, who was born in 1577, may be considered as the last of the alchymists. His death completed the disgrace of the universal medicine. His contemporaries, and those who immediately succeeded him, if we accept Crollius and a few other blind admirers of Paracelsus, attended solely to the improvement of chemiſtry. The chief of them were Agricola, Beguin, Glaser, Erkern, Glauber, Kunckel, Boyle, &c.

Origin of chemistry as a science.

The foundations of the alchymiſtical system being thus shaken, the facts which had been collected soon became a heap of rubbish, and chemistry was left without any fixed principles, and destitute of an object. It was then that a man arose, thoroughly acquainted with the whole of these facts, capable of arranging them, and of perceiving the important purposes to which they might be applied, and able to point out the proper objects to which the researches of chemists ought to be directed. This man was BECCHER. He accomplished the arduous task in his work entitled *Physica Subterranea*, published at Francfort in 1669. The publication of this book forms a very important æra in the history of chemistry. It then escaped for ever from the trammels of alchymy, and became the rudiments of the science which we find it at present.

Ernest Stahl, the editor of the *Physica Subterranea*, adopted, soon after Beccher's death, the theory of his master; but he simplified and improved it so much, that he made it entirely his own; and accordingly it has been always distinguished by the name of the Stahlian Theory.

Its progress

Ever ſince the days of Stahl, chemistry has been cultivated with ardour in Germany and the North ; and the illustrious philosophers of these countries have contributed highly towards its progress and its rapid improvement. The most deservedly celebrated of these are Margraf, Bergman, Scheele, Klaproth, &c.

In France, soon after the establishment of the Academy of Sciences in 1666, Homberg, Geoffroy, and Lemery, acquired celebrity by their chemical experiments and discoveries ; and after the new-modelling of the Academy, chemistry became the peculiar object of a part of that illustrious body. Rouelle, who was made professor of chemistry in Paris about the year 1745, contrived to infuse his own enthuſiasm into the whole body of the French literary men ; and from that moment chemistry became the fashionable study. Men of eminence appeared everywhere, discoveries multiplied, the spirit pervaded the whole nation, extended itself over Italy, and appeared even in Spain.

After the death of Boyle and of some other of the earlier members of the Royal Society, little attention was paid to chemistry in Britain except by a few individuals. The spirit which Newton had infused for the mathematical sciences was so great, that for many years they drew within their vortex almost every man of eminence in Britain. But when Dr Cullen became Professor of chemistry in Edinburgh in 1756, he kindled a flame of enthuſiasm among the students, which was soon spread far and wide by the subsequent discoveries of Black, Cavendish, and Priestley ; and meeting with the kindred fires which were already burning in France, Germany, Sweden, and Italy, the science of chemistry burst forth at once with unexampled lustre. Hence the rapid progress which it has made during the last fifty years, the universal attention which it has excited, and the unexpected light which it has thrown on several of the most important arts and manufactures.

And present state.

The object of this Work is to exhibit as complete a view as poſſible of the present state of chemistry; and to trace, at the same time, its gradual progress from its first rude dawnings as a science, to the improved state which it has now attained. By thus blending the history with the science, the facts will be more eaſily remembered, as well as better understood; and we shall at the same time pay that tribute of respect, to which the illustrious improvers of it are justly intitled.

A complete account of the present state of chemistry must include not merely a detail of the science of chemistry strictly so called, but likewise the application of that science to substances as they exist in nature, constituting the mineral, vegetable, and animal kingdoms. This Work, therefore, will be divided into two Parts. The first will comprehend THE SCIENCE OF CHEMISTRY, properly so called; the second will consist of A CHEMICAL EXAMINATION OF NATURE.

PART I.

PRINCIPLES

OF

CHEMISTRY.

Object of chemistry.

THE object of chemistry is, to ascertain the ingredients of which bodies are composed; to examine the compounds formed by the combination of these ingredients; and to investigate the nature of the power which occasions these combinations.

The science therefore naturally divides itself into three parts: 1 A description of the component parts of bodies, or of *simple substances* as they are called. 2. A description of the compound bodies formed by the union of simple substances. 3. An account of the nature of the power which occasions these combinations. This power is known in chemistry by the name of AFFINITY. These three particulars will form the subject of the three following Books.

BOOK I.

OF

SIMPLE SUBSTANCES.

Book I.

Definition.

By simple substances is not meant what the ancient philosophers called *elements* of bodies, or particles of matter incapable of farther diminution or division. They signify merely bodies which have not been decompounded, and which no phenomenon hitherto observed indicate to be compounds. Very possibly the bodies which we reckon simple may be real compounds; but till this has actually been proved, we have no right to suppose it. Were we acquainted with all the elements of bodies, and with all the combinations of which these elements are capable, the science of chemistry would be as perfect as possible; but at present this is very far from being the case.

Division.

The simple substances at present known amount to about 33, and naturally divide themselves into two classes. The bodies belonging to the first class can be confined in proper vessels, and of course exhibited in a separate state. Those which belong to the second class are of too subtile a nature to be confined by any of the vessels which we possess. They cannot, therefore, be exhibited in a separate state; and their existence is

Book I.

inferred merely from certain phenomena which the first class of bodies and their compounds exhibit in particular circumstances. Hence it is obviously necessary to be acquainted with the properties of the first set of bodies before we can investigate the second. It will be exceedingly convenient to consider these two classes separately. And for want of better terms we shall distinguiſh the first set by the title of *confinable bodies*, the second by that of *unconfinable* bodies *.

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* An apology may be deemed necessary for these two words which have not hitherto been used by any British writer. I employ them because I am acquainted with no English word that expresses the idea which I wish to convey ; namely, that we are able to confine the first set of bodies in vessels, but that the second cannot be confined in any vessel. All the terms that have been hitherto employed to characterize these two sets of bodies convey some hypothesis or other, which in a work of this kind it is necessary as much as possible to avoid.

DIVISION I.

OF

CONFINABLE BODIES.

Division. THE confinable bodies, amounting at present to about 29, may be arranged under the following heads:

1. Oxygen,
2. Simple combustibles,
3. Simple incombustibles,
4. Metals.

Each of these shall be treated of in their order in the four following Chapters.

CHAP. I.

OF OXYGEN.

THE first of these classes includes under it only one substance, *oxygen*; but a substance of so peculiar a nature, that it must be considered separately, and which acts so important a part in the phenomena of chemistry, that it is proper to become acquainted with it as early as possible. It may be obtained by the following process.

Method of procuring oxygen.

Procure an iron bottle of the shape A (fig. 1.) and capable of holding rather more than an English pint. To the mouth of this bottle an iron tube bent like B (fig. 2.) is to be fitted by grinding. A gun barrel deprived of its butt-end answers the purpose remarkably well. Into the bottle put any quantity of the black oxide of manganese * in powder; fix the iron tube into its mouth, and the joining must be air-tight; then put the bottle into a common fire, and surround it on all sides with burning coals. The extremity of the tube must be plunged under the surface of the water with which the vessel C (fig. 3.) is filled. This vessel may be of wood or of japanned tin-plate. It has a wooden shelf

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* This substance shall be afterwards described. It is now very well known in Britain, as it is in common use with bleachers and several other manufacturers, from whom it may be easily procured.

running along two of its sides, about three inches below the top, and an inch under the surface of the water. In one part of this shelf there is a slit, into which the extremity of the iron tube plunges. The heat of the fire expels the greatest part of the air contained in the bottle. It may be perceived bubbling up through the water of the vessel C from the extremity of the iron tube. At firſt the air-bubbles come over in torrents, but after having continued for some time they cease altogether. Meanwhile the bottle is becoming gradually hotter. When it is obscurely red the air-bubbles make their appearance again, and become more abundant as the heat encreases. This is the signal for placing the glass jar D, open at the lower extremity, previously filled with water, so as to be exactly over the open end of the gun barrel. The air-bubbles ascend to the top of the glass jar D, and gradually displace all the water. The glass jar D then appears to be empty, but is in fact filled with air. It may be removed in the following manner: Slide it away a little from the gun-barrel, and then dipping any flat dish into the water below it, raise it on the dish, and bear it away. The dish must be allowed to retain a quantity of water in it, to prevent the air from escaping (see fig. 4.) Another jar may then be filled with air in the same manner; and this process may be continued either till the manganese ceases to give out air, or till as many jarfuls have been obtained as are required. This method of obtaining and confining air was first invented by Dr Mayow, and afterwards much improved by Dr Hales. All the airs obtained by this or any other process, or, to speak more properly, all the airs differing in their properties from the air of the atmosphere, have, in order to distinguish them from it, been called *gases ;* and this name we shall afterwards employ [*].

Oxygen gas may be obtained likewise by the following process :

Another method.

D (in fig. 5.) represents a wooden trough, the inſide of which is lined with lead or tinned copper. C is the cavity of the trough, which ought to be a foot deep. It is to be filled with water at least an inch above the shelf AB, which runs along the inſide of it, about three inches from the top. In the body of the trough, which may be called the cistern, the jars destined to hold gas are to be filled with water, and then to be lifted, and placed inverted upon the shelf at B. This trough, which was invented by Dr Priestley, has been called by the French chemists the *pneumato-chemical,* or simply *pneumatic* apparatus, and is extremely useful in all experiments in which gases are concerned. Into the glass-vessel E put a quantity of the black oxide of manganese in powder, and pour over it as much of that liquid which in commerce is called *oil of vitriol,* and in chemistry *sulphuric acid,* as is sufficient to form the whole into a thin paste. Then insert into the mouth of the vessel the glass tube F, so closely that no air can escape except through the tube. This may be done either by grind-

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[*] The word *gas* was first introduced into chemistry by Van Helmont. He seems to have intended to denote by it every thing which is driven off from bodies in the state of vapour by heat. He divides *gases* into five classes " Nescivit inquam schola Galenica hactenus differentiam inter gas ventosum (quod mere aer est, id est, ventus, per syderum blas commotus), gas pingue, gas siccum, quod sublimatum dicitur, gas fuliginosum, sive endimicum, et gas sylvestre, sive incoercibile, quod in corpus cogi non potest visibile." *Van Helmont De Flatibus,* § 4.

ing, or by covering the joining with a little glazier's putty, and then laying over it slips of bladder or linen dipped in glue or in a mixture of the white of eggs and quicklime. The whole must be made fast with cord *. The end of the tube F is then to be plunged into the pneumatic apparatus D and the jar G, previously filled with water, to be placed over it on the shelf. The whole apparatus being fixed in that situation, the glass vessel E is to be heated by means of a lamp or a candle. A quantity of oxygen gas rushes along the tube F, and fills the jar G. As soon as the jar is filled, it may be slid to another part of the shelf, and other jars substituted in its place, till as much gas has been obtained as is wanted. Both these methods of obtaining oxygen gas were discovered by Scheele †.

Discovered by Priestley and Scheele.

The gas which we have obtained by the above processes was discovered by Dr Priestley on the 1st of August 1774, and called by him *dephlogisticated air*. Mr Scheele of Sweden discovered it in 1775, without any previous knowledge of what Dr Priestley had done:

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* This process, by which the joinings of vessels are made air-tight, is called *luting*, and the substances used for that purpose are called *lutes*. The lute most commonly used by chemists, when the vessels are exposed to heat, is fat lute, made by beating together in a mortar fine clay and boiled linseed oil. Bees wax, melted with about one-eighth part of turpentine, answers very well, when the vessels are not exposed to heat. The accuracy of chemical experiments depends almost entirely in many cases upon securing the joinings properly with luting. The operation is always tedious; and some practice is necessary before one can succeed in luting accurately. Some very good directions are given by Lavoisier. See his *Elements*, Part iii. chap. 7 In many cases luting may be avoided altogether, by using glass-vessels properly fitted to each other by grinding them with emery.

† On Fire.

he gave it the name of *empyreal air*. Condorcet gave it first the name of *vital air*; and Mr Lavoisier afterwards called it *oxygen gas*; a name which is now generally received, and which we shall adopt.

Properties of oxygen

1. Oxygen gas is colourless, and invisible like common air. Like it, too, it is elastic, and capable of indefinite expansion and compression.

Supports flame

2. If a lighted taper be let down into a phial filled with oxygen gas, it burns with such splendour that the eye can scarcely bear the glare of light, and at the same time produces a much greater heat than when burning in common air. It is well known that a candle put into a well-closed jar filled with common air is extinguished in a few seconds. This is the case also with a candle inclosed in oxygen gas; but it burns much longer in an equal quantity of that gas than of common air.

And life.

3. It was proved long ago by Boyle, that animals cannot live without air, and by Mayow that they cannot breathe the same air for any length of time without suffocation. Dr Priestley and several other philosophers have shewn us, that animals live much longer in the same quantity of oxygen gas than of common air. Count Morozzo placed a number of sparrows, one after another, in a glass bell filled with common air, and inverted over water.

	H.	M.
The first sparrow lived	3	0
The second	0	3
The third	0	1

He filled the same glass with oxygen gas, and repeated the experiment.

	H.	M.
The first sparrow lived	5	23
The second	2	10
The third	1	30
The fourth	1	10
The fifth	0	30
The sixth	0	47
The seventh	0	27
The eighth	0	30
The ninth	0	22
The tenth	0	21

He then put in two together; the one died in 20 minutes, but the other lived an hour longer.

Exists in the atmosphere.

4. It has been ascertained by experiments, which shall be afterwards related, that atmospherical air contains between 20 and 30 parts in the hundred of oxygen gas; and that no substance will burn in common air previously deprived of all the oxygen gas which it contains. But combustibles burn with great splendour in oxygen gas, or in other gases to which oxygen gas has been added. Oxygen, gas, then, is absolutely necessary for combustion.

5. It has been proved also, by many experiments, that no breathing animal can live for a moment in any air or gas which does not contain oxygen mixed with it. Oxygen gas, then, is absolutely necessary for respiration.

6. When substances are burnt in oxygen gas, or in any other gas containing oxygen, if the air be examined after the combustion, we shall find that a great part of the oxygen has disappeared. If charcoal, for instance, be burnt in oxygen gas, there will be found, instead of part of the oxygen, another very different gas, known

by the name of carbonic acid gas. Exactly the same thing takes place when air is respired by animals; part of the oxygen gas disappears, and its place is occupied by substances possessed of very different properties. Oxygen gas then undergoes some change during combustion, as well as the bodies which have been burnt; and the same observation applies also to respiration.

Its specific gravity.

7. The specific gravity of oxygen gas, as determined by Mr Kirwan *, is 0.00135, that of water being 1.0000, as is always the case when specific gravity is mentioned absolutely. It is therefore 740 times lighter than the same bulk of water. According to this estimate, its weight to atmospherical air is as 1103 to 1000. One hundred cubic inches of common air weigh 31 grs.; and 100 cubic inches of oxygen gas weigh 34 grs.; the barometer being at 30 inches, and the thermometer at 60°. The experiments of Lavoisier coincide almost exactly with those of Kirwan: But Mr Davy makes the weight of 100 cubic inches of oxygen gas 35.06 grains †.

Combination with water.

8. Oxygen gas is not *sensibly* absorbed by water though jarfuls of it be left in contact with that liquid. It has been ascertained, however, that water does in reality absorb a small portion of it, though not enough to occasion any perceptible diminution in the bulk of the gas. By forcing oxygen gas into a bottle of water by means of strong pressure, the water may be made to absorb about half its bulk of that gas, and to retain it in solution. This experiment was first made by Mr Paul, a celebrated preparer of mineral waters, now set-

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* On Phlogiston, Sect. i.

† Davy 's Researches, p. 365.

tled in London. Water thus impregnated does not sensibly differ from common water either in taste or smell, yet it has been found a valuable remedy in several diseases *.

Affinity explained.

9. Oxygen is capable of combining with a great number of bodies, and of forming compounds. As the combination of substances with each other is of the utmost importance in chemistry, before we proceed farther it will be proper to explain it. When common salt is thrown into a vessel of pure water, it melts, and very soon spreads itself through the whole of the liquid, as any one may convince himself by the taste. In this case the salt is combined with the water, and cannot afterwards be separated by filtration or any other method merely mechanical. It may, however, by a very simple process: Pour into the solution a quantity of spirit of wine, and the salt falls slowly to the bottom in the state of a very fine powder.

Why does the salt dissolve in water? and why does it fall to the bottom on pouring in spirit of wine? These questions were first answered by Sir Isaac Newton. There is a certain attraction between the particles of common salt and those of water, which causes them to unite together whenever they are presented to one another. There is an attraction also between the particles of water and of spirit of wine, which equally disposes them to unite, and this attraction is greater than that between the water and salt; the water therefore leaves the salt to unite with the spirit of wine, and the

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* See Dr Odier's observations on it in the 8th and 10th vols of the Bibliotheque Britannique; and the Appendix to Mr Paul's little publication on his Artificial Mineral Waters.

Chap. I.

salt being now unsupported, falls to the ground by its gravity. This power, which disposes the particles of different bodies to unite, was called by Newton *attraction*, by Bergman *elective attraction*, and by many of the German and French chemists *affinity* *; and this last term is now employed in preference, because the other two are rather general. All substances which are capable of combining together are said to have an *affinity for* each other: those substances, on the contrary, which do not unite, are said to have *no affinity* for each other. Thus it is said that there is no affinity between water and oil. It appears from the instance of the common salt and spirit of wine, that substances differ in the degree of their affinity for other substances, since the spirit of wine displaced the salt and united with the water. Spirit of wine therefore has a stronger affinity for water than common salt has.

In 1719, Geoffroi invented a method of representing the different degrees of affinities in tables, which he called *tables of affinity*. His method consisted in placing the substance whose affinities were to be ascertained at the top of a column, and the substances with which it united below it, each in the order of its affinity; the substance which had the strongest affinity next it, and that which had the weakest farthest distant, and so of the rest. According to this method, the affinity of water for spirit of wine and common salt would be marked as follows:

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* The word *affinity* seems first to have been introduced into science by Dr Hooke. See his Micrographia.

Book I.
Division I.

WATER.

Spirit of wine
Common salt.

This method has been universally adopted, and has contributed very much to the rapid progress of chemistry.

I shall proceed therefore to give a table of the affinities of oxygen.

Affinities of oxygen.

OXYGEN.

Charcoal,
Titanium,
Manganese,
Zinc,
Iron,
Tin*,
Uranium,
Molybdenum,
Tungstic,
Cobalt,
Antimony,
Hydrogen,
Phosphorus,
Sulphur,
Azote,
Nickel,
Arsenic,
Chromium,
Bismuth,

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* Bouillon La Grange, Ann. de Chim. xxxv. 28.

Lead,
Copper,
Tellurium,
Platinum,
Mercury,
Silver,
Oxide of arsenic,
Nitrous gas,
Gold,
Muriatic acid,
White oxide of manganese,
White oxide of lead.

The reason of this order will appear when the substances themselves come to be treated of.

CHAP. II.

OF SIMPLE COMBUSTIBLES.

BY *combustibles*, I mean substances capable of combustion; and by *simple combustibles*, bodies of that nature which have not hitherto been decompounded. These bodies are only four in number; namely, SULPHUR, PHOSPHORUS, CARBON, and HYDROGEN. The metals might indeed be classed among combustible bodies; but the greater number of their properties are so different from those of the four bodies just mentioned, that it is proper to consider them by themselves as a distinct class of bodies. All our classifications are in fact artificial; Nature does not know them, and will not submit to them. They are useful, however, as they enable us to learn a science sooner, and to remember it better; but if we mean to derive these advantages from them, we must renounce a rigid adherence to arbitrary definitions, which Nature disclaims.

Number.

SECT. I.

OF SULPHUR.

Sulphur, distinguished also in English by the name of *brimstone*, was known in the earliest ages. As it is found native in many parts of the world, it could not fail very soon to attract the attention of mankind. It was used by the ancients in medicine, and its fumes were employed in bleaching wool [*].

Properties.

1. Sulphur is a hard brittle substance, commonly of a yellow colour, without any smell, and of a weak though perceptible taste.

It is a non-conductor of electricity, and of course becomes electric by friction. Its specific gravity is 1.990.

Sulphur undergoes no change by being allowed to remain exposed to the open air. When thrown into water, it does not melt as common salt does, but falls to the bottom, and remains there unchanged: It is therefore insoluble in water.

Action of heat.

2. If a considerable piece of sulphur be exposed to a sudden though gentle heat, by holding it in the hand, for instance, it breaks to pieces with a crackling noise.

Flowers of sulphur.

When sulphur is heated to the temperature of about 170°, it rises up in the form of a fine powder, which may be easily collected in a proper vessel. This powder is called *flowers of sulphur* [†]. When substances fly

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[*] Pliny, lib. xxxv. c. 15.

[†] It is only in this state that sulphur is to be found in commerce to-

off in this manner on the application of a moderate heat, they are called *volatile* ; and the process itself, by which they are raised, is called *volatilization*.

When heated to the temperature of 212° of Fahrenheit's thermometer, it melts and becomes as liquid as water. If this experiment be made in a thin glass vessel, of an egg shape, and having a narrow mouth*, the vessel may be placed upon burning coals without much risk of breaking it. The strong heat soon causes the sulphur to boil, and converts it into a brown coloured vapour, which fills the vessel, and issues with considerable force out from its mouth.

Sulphur capable of crystallizing.

3. There are a great many bodies which, after being dissolved in water or melted by heat, are capable of assuming certain regular figures. If a quantity of common salt, for instance, be dissolved in water, and that fluid, by the application of a moderate heat, be made to fly off in the form of steam ; or, in other words, if the water be slowly *evaporated*, the salt will fall to the bottom of the vessel in cubes. These regular figures are called *crystals*. Now sulphur is capable of crystallizing. If it be melted, and as soon as its surface begins to congeal, the liquid sulphur beneath be poured out, the internal cavity will exhibit long needle-shaped crystals of an octahedral figure. This method of crystallizing sulphur was contrived by Rouelle. If the experiment be made in a glass vessel, or upon a flat plate of iron, the crystals will be perceived beginning to shoot when the temperature sinks to 220°.

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lerably pure ; *roll sulphur* usually contains a considerable portion of foreign bodies.

* Such vessels are usually called *receivers* or *flasks* by chemists.

4. If sulphur be kept melted in an open vessel, it becomes gradually thick and viscid. When in this state, if it be poured into a bason of water, it will be found to be of a red colour, and as soft as wax. In this state it is employed to take off impressions from seals and medals. These casts are known in this country by the name of *sulphurs*. When exposed to the air for a few days, the sulphur soon recovers its original brittleness, but it retains its red colour. It is supposed at present, that sulphur, rendered viscid and red by a long fusion, has combined with a little oxygen. It is therefore no longer pure sulphur, but a compound of sulphur and oxygen. Mr Fourcroy, a celebrated French chemist, who has contributed with much zeal and success to the rapid improvement of chemistry, has given it, when in this state, the name of *oxide of sulphur*.

Oxide of sulphur,

5. When sulphur is heated to the temperature of 560° in the open air, it takes fire spontaneously, and burns with a pale blue flame, and at the same time emits a great quantity of fumes of a very strong suffocating odour. When set on fire and then plunged into a jar full of oxygen gas, it burns with a bright reddish white flame, and at the same time emits a vast quantity of fumes. If the heat be continued long enough, the sulphur burns all away without leaving any ashes or *residuum*. If the fumes be collected, they are found to consist entirely of *sulphuric acid*. By combustion, then, sulphur is converted into an acid*. This fact was

Converted by combustion into an acid.

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* Acids are a class of compound bodies, to be afterwards described. They are distinguished by a sour taste, and by the property which they

known several centuries ago, but no intelligible explanation was given of it till the time of Stahl. That chemist undertook the task, and founded on his experiments a theory so exceedingly ingenious, and supported by such a vast number of facts, that it was in a very short time adopted with admiration by the philosophic world, and contributed not a little to raise chemistry to that rank among the sciences from which the ridiculous pretensions of the early chemists had excluded it.

Stahl's explanation of this.

According to Stahl, there is only one substance in nature capable of combustion, which therefore he called PHLOGISTON; and all those bodies which can be set on fire contain less or more of it. Combustion is merely the separation of this substance. Those bodies which contain none of it are of course incombustible. All combustibles, except those which consist of pure phlogiston (if there be any such), are composed of an incombustible body and phlogiston united together. During combustion the phlogiston flies off, and the incombustible body remains behind. Now when sulphur is burnt, the substance which remains is sulphuric acid, an incombustible body. Sulphur therefore is composed of sulphuric acid and phlogiston.

To establish this theory completely, it was necessary to shew that sulphuric acid can be obtained by separating the phlogiston from sulphur, and that sulphur can be actually formed by combining together sulphuric acid and phlogiston. Both of these points Stahl undertook

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possess of changing the blue colour of many vegetable infusions (of the flowers of mallows for instance, or red cabbage) to red.

Chap. II.

to demonstrate. If potass* and sulphur be mixed together and heated, they melt and form a brittle mass of a brown colour, consisting of the two substances combined together. Put this compound previously reduced to powder, into a flat open vessel, and expose it to a gentle fire. The sulphur gradually disappears, and sulphuric acid is found in its place combined with the potass. In this case, said Stahl, the gentle heat dissipates the phlogiston and leaves the acid. To form the sulphur anew, it is only necessary to present to the acid a body containing phlogiston. Lamp black or charcoal is such a body, for it is combustible: and therefore, according to the theory of Stahl, contains phlogiston: when burnt, it leaves a very inconsiderable residuum, and consequently contains hardly any thing else than phlogiston. He mixed together in a crucible the compound, consisting of sulphuric acid and potass, and one-fourth part by weight of pounded charcoal, covered the crucible with another inverted over it, and applied a strong heat to it. He then allowed it to cool, and examined its contents. The charcoal had disappeared, and there only remained in the crucible a mixture of potass and sulphur combined together, and of a darker colour than usual, from the residuum of the charcoal. Now there were only three substances in the crucible at first, potass, sulphuric acid, and charcoal; two of these have disappeared, and *sulphur* has been found in their place. Sulphur then must have been formed by the combination of these two. But charcoal consists of phlogiston and a very small residuum, which is still

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* The nature of *potass* shall afterwards be explained. It is the *potash* well known in commerce in a state of purity.

found in the crucible. The sulphur then must have been formed by the combination of sulphuric acid and phlogiston.* This simple and luminous explanation appeared so satisfactory, that the composition of sulphur was long considered as one of the best demonstrated truths in chemistry.

Unsatisfactory.

There are two facts, however, which Stahl either did not know, or did not sufficiently attend to, neither of which were accounted for by his theory. The first is, that sulphur will not burn if air be completely excluded ; the second, that sulphuric acid is heavier than the sulphur from which it was produced.

To account for these, or facts similar to these, succeeding chemists refined upon the theory of Stahl, deprived his phlogiston of *gravity*, and even assigned it a principle of *levity*. Still, however, the necessity of the contact of air remained unexplained At last Mr Lavoisier, who had already distinguished himself by the extensiveness of his views, the accuracy of his experiments, and the precision of his reasoning, undertook the examination of this subject, and his experiments were published in the Memoirs of the Academy of Sciences for 1777. He put a quantity of sulphur into a large glass vessel filled with air, which he inverted into another vessel containing mercury, and then set fire to the sulphur by means of a burning-glass. It emitted a blue flame, accompanied with thick vapours, but was very soon extinguished, and could not be again kindled. There was, however, a little sulphuric acid formed, which was a good deal heavier than the sul-

Real explanation by Lavoisier.

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* Stahl's *Opusc. Chymico-physico-med.* Anatomia Sulphuris Comm. p. 749.

Chap. II.

phur which had disappeared; there was also a diminution in the air of the vessel proportional to this increase of weight. The sulphur, therefore, during its conversion into an acid, must have absorbed part of the air. He then put a quantity of sulphuret of iron, which consists of sulphur and iron combined together, into a glass vessel full of air, which he inverted over water*. The quantity of air in the vessel continued diminishing for eighteen days, as was evident from the ascent of the water to occupy the space which it had left; but after that period no further diminution took place. On examining the sulphuret, it was found somewhat heavier than when first introduced into the vessel, and the air of the vessel wanted precisely the same weight. Now this air had lost all its oxygen; consequently the whole of that oxygen must have entered into the sulphuret. Part of the sulphur was converted into sulphuric acid; and as all the rest of the sulphuret was unchanged, the whole of the increase of weight must have been owing to something which had entered into that part of the sulphur which was converted into acid. This something we know was oxygen. Sulphuric acid therefore must be composed of sulphur and oxygen; for as the original weight of the whole contents of the vessel remained exactly the same, there was not the smallest reason to suppose that any substance had left the sulphur.

It is impossible, then, that sulphur can be composed of sulphuric acid and phlogiston, as Stahl supposed, since sulphur itself enters as a part into the composition of that acid. There must therefore have been

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* This experiment was first made by Scheele, but with a different view.

some want of accuracy in the experiment by which Stahl proved the composition of sulphur, or at least some fallacy in his reasonings; for it is impossible that there can be two contradictory facts. Upon examining the potass and sulphur produced by Stahl's experiment, we find them to be considerably lighter than the charcoal, sulphuric acid, and potass originally employed. Something therefore has made its escape during the application of the heat. And if the experiment be conducted in a close vessel, with a pneumatic apparatus attached to it, a quantity of gas will be obtained exactly equal to the weight which the substances operated on have lost; and this weight considerably exceeds that of all the charcoal employed. This gas is *carbonic acid gas*, which is composed of charcoal and oxygen, as will afterwards appear. We now perceive what passes in this experiment: Charcoal has a stronger affinity for oxygen at a high temperature than sulphur has. When charcoal therefore is presented to sulphuric acid in that temperature, the oxygen of the acid combines with it, they fly off in the form of carbonic acid gas, and the sulphur is left behind. In Stahl's first experiment, the change of sulphur into sulphuric acid was obviously owing to the absorption of oxygen from the air. Hence the reason why the mixture must be placed in an open vessel.

The combustion of sulphur, then, is nothing else than the act of its combination with oxygen; and for any thing which we know to the contrary, it is a simple substance.

6. The affinities of sulphur, according to Bergman, are as follows:

Affinities of sulphur.

Fixed alkalies,
Iron,
Copper,
Tin,
Lead,
Silver,
Bismuth,
Antimony,
Mercury,
Arsenic,
Molybdenum.

SECT. II.

OF PHOSPHORUS.

Method of preparing phosphorus.

PHOSPHORUS may be procured by the following process: Let a quantity of bones be burnt, or, as it is termed in chemistry, *calcined*, till they cease to smoke, or to give out any odour, and let them afterwards be reduced to a fine powder. Put 100 parts of this powder into a bason of porcelain or stoneware, dilute it with four times its weight of water, and then add gradually (stirring the mixture after every addition) 40 parts of sulphuric acid. The mixture becomes hot, and a vast number of air-bubbles are extricated *. Leave the mixture in this state for 24 hours; taking

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* The copious emission of air-bubbles is called in chemistry *effervescence*.

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care to stir it well every now and then with a glass or porcelain rod to enable the acid to act upon the powder*.

The whole is now to be poured on a filter of cloth; the liquid which runs through the filter is to be received in a porcelain bason; and the white powder which remains on the filter, after pure water has been poured on it repeatedly, and allowed to strain into the porcelain bason below, being of no use, may be thrown away.

Into the liquid contained in the porcelain bason, which has a very acid taste, sugar of lead, dissolved in water, is to be poured slowly; a white powder immediately falls to the bottom: the sugar of lead must be added as long as any of this powder continues to be formed. Throw the whole upon a filter. The white powder which remains upon the filter is to be well washed, allowed to dry, and then mixed with about one-sixth of its weight of charcoal powder. This mixture is to be put into the earthen ware retort (fig. 5.) The retort is to be put into a sand bath †, and the beak of it plunged into a vessel of water, so as to be just under the surface. The whole of the apparatus is represented in fig. 6. Heat is now to be applied gradually till the retort be made red hot. A vast number of air-bubbles issue from the beak of the retort, some of which take fire when they come to the surface of the water. At

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* Fourcroy and Vauquelin, *Mem. de l'Inst.* ii. 282.

† By a *sand bath* is meant, in chemistry, an iron pot (or any similar vessel) filled with sand. Glass or porcelain vessels are plunged into the sand, and then heat is applied to the pot. The use of the sand is to apply the heat more equally; in consequence of which, the vessels are not so apt to crack and break.

last there drops out a substance which has the appearance of melted wax, and which congeals under the water [*]. This substance is *phosphorus*.

History of its discovery.

It was accidentally discovered by Brandt, a chemist of Hamburgh, in the year 1669 [†], as he was attempting to extract from human urine a liquid capable of converting silver into gold. He showed a specimen of it to Kunkel, a German chemist of considerable eminence, who mentioned the fact as a piece of news to one Kraft, a friend of his at Dresden. Kraft immediately repaired to Hamburgh, and purchased the secret from Brandt for 200 dollars, exacting from him at the same time a promise not to reveal it to any other person. Soon after, he exhibited his phosphorus publicly in Britain and France, expecting doubtless that it would make his fortune. Kunkel, who had mentioned to Kraft his intention of getting possession of the process, being vexed at the treacherous conduct of his friend, attempted to discover it himself; and about the year 1674 he succeeded, though he only knew from Brandt that urine was the substance from which phosphorus had been procured [‡]. Accordingly he is always reckoned, and deservedly too, as one of the discoverers of phosphorus.

Boyle likewise discovered phosphorus. Leibnitz indeed affirms, that Kraft taught Boyle the whole process, and Kraft declared the same thing to Stahl. But surely the assertion of a dealer in secrets, and one who

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[*] The theory of this process will be explained afterwards.

[†] Homberg, *Mem. Par.* 1692.

[‡] This is Kunkel's own account. See his *Laboratorium Chymicum*, p. 660. See also Wiegleb's *Geschichte des Wachsthums und der Erfindungen in der Chemie*, vol. i. p. 41.

had deceived his own friend, on which the whole of this story is founded, cannot be put in competition with the affirmation of a man like Boyle, who was not only one of the greatest philosophers, but likewise one of the most virtuous men of his age; and he positively assures us, that he made the discovery without being previously acquainted with the process *.

Mr Boyle revealed the process to Godfrey Hankwitz, a London apothecary, who continued for many years to supply all Europe with phosphorus. Hence it was known to chemists by the name of *English phosphorus*. Other chemists, indeed, had attempted to produce it, but seemingly without success †, till in 1737 a stranger appeared in Paris, and offered to make phosphorus. The French government granted him a reward for communicating his process. Hellot, Dufay, Geoffroy, and Duhamel, saw him execute it with success; and Hellot published a very complete account of it in the Memoirs of the French Academy for 1737. This process was much improved in 1740 by Margraf ‡; but it still continued very tedious, expensive, and disgusting.

In the year 1769, Gahn, a Swedish chemist, discovered, that phosphorus is contained in bones §; and Scheele ‖, very soon after, invented a process for obtaining it from them. Phosphorus is now generally

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* Boyle's *Works* abridged by Shaw, iii. 174.

† Stahl's *Fundament. Chym.* ii. 58.

‡ *Miscel Berolin.* 1740, iii. 294. and *Mem. Acad. Berlin*, 1746, 289.

§ Bergman's *Notes on Scheffer*.

‖ Crell, in his life of Scheele, informs us, that Scheele himself was the discoverer of the fact. This, he says, appears clearly from a printed letter of Scheele to Gahn, who was before looked upon as the discoverer. See Crell's *Annals*, English Trans. i. 17.

procured in that manner. The process described in the beginning of this Section is that of Fourcroy and Vauquelin: it differs from that of Scheele, as will appear afterwards, in several particulars.

Its properties.

1. Phosphorus, when pure, is semi-transparent, and of a yellowish colour; but when kept some time in water, it becomes opaque externally, and then has a great resemblance to white wax. Its consistence is nearly that of wax: it may be cut with a knife, or twisted to pieces with the fingers. It is insoluble in water. Its mean specific gravity is 1.770.

2. It melts at the temperature of 99° †. Care must be taken to keep phosphorus under water when melted; for it is so combustible, that it cannot easily be melted in the open air without taking fire. When phosphorus is newly prepared, it is always dirty, being mixed with a quantity of charcoal dust and other impurities. These impurities may be separated by melting it under water, and then squeezing it through a piece of clean shamoy leather. It may be formed into sticks, by puting it into a glass funnel with a long tube, stopped at the bottom with a cork, and plunging the whole under warm water. The phosphorus melts, and assumes the shape of the tube. When cold, it may be easily pushed out with a bit of wood.

If air be excluded, phosphorus evaporates at 219°, and boils at 554° ‡.

Burns when exposed to the air.

3. When phosphorus is exposed to the atmosphere, provided the temperature be not lower than 43°, it emits a white smoke, which has the smell of garlic, and is

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† Pelletier, *Journal de Physique*, xxxv. 380.

‡ Ibid. p. 381.

luminous in the dark. This smoke is more abundant the higher the temperature is, and is occasioned by the gradual combustion of the phosphorus, which at last disappears altogether.

4. When a bit of phosphorus is put into a glass jar filled with oxygen gas, part of the phosphorus is dissolved by the gas at the temperature of 60°; but the phosphorus does not become luminous unless its temperature be raised to 80°[*]. Hence we learn, that phosphorus burns at a lower temperature in common air than in oxygen gas. This slow combustion of phosphorus, at the common temperature of the atmosphere, renders it necessary to keep phosphorus in phials filled with water. The water should be previously boiled to expel a little air, which that liquid usually contains. The phials should be kept in a dark place; for when phosphorus is exposed to the light, it soon becomes of a white colour, which gradually changes to a dark brown. When thus altered, the French chemists give it the name of *oxide of phosphorus*; supposing it now to be no longer pure phosphorus, but phosphorus combined with a little oxygen. Phosphorus, when newly prepared, always contains some of this oxide of phosphorus mixed with it; but it may be easily separated by plunging the mass into water heated to about 100 . The phosphorus melts, while the oxide remains unchanged, and swims upon the surface of the melted phosphorus.

Converted by combustion

5. When heated to 148°, phosphorus takes fire and burns with a very bright flame, and gives out a great quantity of white smoke, which is luminous in the

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[*] Fourcroy and Vauquelin, *Annales de Chimie*, xxi. 196.

dark; at the same time it emits an odour which has some resemblance to that of garlic. It leaves no residuum; but the white smoke, when collected, is found to be an *acid*. Stahl considered this acid as the muriatic [*]. According to him, phosphorus is composed of muriatic acid and phlogiston, and the combustion of it is merely the separation of phlogiston. He even declared, that to make phosphorus, nothing more is necessary than to combine muriatic acid and phlogiston; and that this composition is as easily accomplished as that of sulphur itself [†].

Into phosphoric acid,

These assertions having gained implicit credit, the composition and nature of phosphorus were considered as completely understood, till Margraf of Berlin published his experiments in the year 1740. That great man, one of those illustrious philosophers who have contributed so much to the rapid increase of the science, distinguished equally by the ingenuity of his experiments and the clearness of his reasoning, attempted to produce phosphorus by combining together phlogiston and muriatic acid; but though he varied his process a thousand ways, presented the acid in many different states, and employed a variety of substances to furnish phlogiston, all his attempts failed, and he was obliged to give up the combination as impracticable. On examining the acid produced during the combustion of phosphorus, he found that its properties were very different from those of muriatic acid. It was therefore a distinct substance. The name of *phosphoric acid* was

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[*] This acid shall be afterwards described.

[†] Stahl's *Three Hundred Experiments*.

given to it; and it was concluded that phosphorus is composed of this acid united to phlogiston.

But it was observed in 1772 by Morveau [*], that phosphoric acid is heavier than the phosphorus from which it was produced [†]; and Boyle had long before shewn that phosphorus would not burn except when in contact with air. These facts were sufficient to prove the inaccuracy of the theory concerning the composition of phosphorus; but they remained themselves unaccounted for, till Lavoisier published those celebrated experiments which threw so much light on the nature and composition of acids [‡].

Which is phosphorus combined with oxygen.

He exhausted a glass globe of air by means of an air-pump; and after weighing it accurately, he filled it with oxygen gas, and introduced into it 100 grains of phosphorus. The globe was furnished with a stop-cock, by which oxygen gas could be admitted at pleasure. He set fire to the phosphorus by means of a burning glass. The combustion was extremely rapid, accompanied by a bright flame and much heat. Large quantities of white flakes attached themselves to the inner surface of the globe, and rendered it opaque; and these at last became so abundant, that notwithstanding the constant supply of oxygen gas, the phosphorus was extinguished. The globe, after being allowed to cool, was again weighed before it was opened. The quantity of oxygen employed during the experiment was ascertained, and the phosphorus, which still remained unchanged, accu-

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[*] *Digress. Academ.* p. 253.

[†] The same observation had been made by Margraf, but no attention was paid to it.

[‡] *Mem. Par.* 1778 and 1780.

rately weighed. The white flakes, which were nothing else than pure phosphoric acid, were found exactly equal to the weights of the phosphorus and oxygen, which had disappeared during the process. Phosphoric acid therefore must have been formed by the combination of these two bodies; for the absolute weight of all the substances together was the same after the process as before it *. It is impossible then for phosphorus to be composed of phosphoric acid and phlogiston, as phosphorus itself enters into the composition of that acid.

Thus the combustion of phosphorus, like that of sulphur, is nothing else than its combination with oxygen: for during the process no new substance appears, except the acid, accompanied indeed with much heat and light.

Phosphuret of sulphur.

6. Phosphorus combines readily with sulphur, as Margraf discovered during his experiments on phosphorus. This combination was afterwards examined by Mr Pelletier. The two substances are capable of being mixed in different proportions. Seventy-two grains of phosphorus and nine of sulphur, when heated in about four ounces of water, melt with a gentle heat. The compound remains fluid till it be cooled down to 77°, and then becomes solid †. These substances were combined in the same manner in the following proportions:

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* Lavoisier's *Chemistry*, Part I. chap. v.

† Some caution is necessary in the preparation of this compound. For if it be heated suddenly under water it explodes with considerable violence, flies out of the vessel, driving before it all the water, and burning with great brilliancy. The explosion is owing to the rapid formation of two gases, to be afterwards described. They are called *sulphuretted hydrogen gas* and *phosphuretted hydrogen gas*.

4 Phosphor. 1 Sulphur	congeals at	59°
4 Phosphor. 2 Sulphur	. . . . . . at	50°
4 Phosphor. 4 Sulphur	. . . . . . at	41°
4 Phosphor. 12 Sulphur	. . . . . . at	99°

When the phosphorus predominates, this compound is called *phosphuret of ſulphur;* when the sulphur exceeds, it is called *sulphuret of phosphorus.*

Phosphorus and sulphur may be combined also by melting them together without any water; but the combination takes place so rapidly, that they are apt to rush out of the vessel if the heat be not exceedingly moderate *.

7. Phosphorus is capable likewise of combining with many other bodies: the compounds produced are called *phosphurets*

A poison.

8. Phosphorus, when used internally, is poisonous †. In very small quantities (as one-fourth of a grain), when very minutely divided, it is said by Leroi to be very efficacious in restoring and esablishing the force of young persons exhausted by sensual indulgence ‡; that is, I suppose, in exciting the venereal appetite.

The affinities of phosphorus have not yet been ascertained.

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* Pelletier, *Jour. de Phys.* xxxv. 382.

† *Ann. de Chim.* xxvii. 87.

‡ Nicholson's *Journal*, iii. 85.

SECT. III.

OF CARBON OR DIAMOND.

Method of preparing charcoal.

If a piece of wood be put into a crucible, well covered with sand, and kept red hot for some time, it is converted into a black shining brittle substance, without either taste or smell, well known under the name of *charcoal*. Its properties are the same from whatever wood it has been obtained, provided it be exposed for an hour in a covered crucible to the heat of a forge *.

Its properties.

1. Charcoal is insoluble in water. It is not affected (provided that all air and moisture be excluded) by the most violent heat which can be applied, excepting only that it is rendered much harder and more brilliant.

It is an excellent conductor of electricity, and possesses besides a number of singular properties which render it of considerable importance. It is incapable of putrefying or rotting like wood, and is not therefore liable to decay by age. This property has been long known. It was customary among the ancients to *char* the outside of those stakes which were to be driven into the ground or placed in water, in order to preserve the wood from spoiling. New-made charcoal, by being rolled up in cloths which have contracted a disagreeable odour, effectually destroys it. When boiled with meat

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* Unless that precaution be attended to, the properties of charcoal differ considerably. The cause of this will be considered in the third Chapter of the second Book of this work.

beginning to putrefy, it takes away the bad taint. It is perhaps the best teeth-powder known. Mr Lowitz of Petersburgh has shewn, that it may be used with advantage to purify a great variety of substances.

Absorbs water, air, and oxygen.

2. New-made charcoal absorbs moisture with avidity. When heated to a certain temperature, it absorbs air copiously. La Metherie plunged a piece of burning charcoal into mercury, in order to extinguish it, and introduced it immediately after into a glass vessel filled with common air. The charcoal absorbed four times its bulk of air. On plunging the charcoal into water, one-fifth of this air was disengaged. This air, on being examined, was found to contain a much smaller quantity of oxygen than atmospherical air does. He extinguished another piece of charcoal in the same manner, and then introduced it into a vessel filled with oxygen gas. The quantity of oxygen gas absorbed amounted to eight times the bulk of the charcoal; a fourth part of it was disengaged on plunging the charcoal into water *.

This property of absorbing air, which new made charcoal possesses, was observed by Fontana, Priestley, Scheele, and Morveau; but Morozzo was the first philosopher who published an accurate set of experiments on the subject. He plunged a piece of red hot-charcoal, 12 lines long and 8 in diameter, into a bason of mercury, and then made it ascend into a glass tube standing over the mercury. The tube was 144 lines long and 12 in diameter, and was filled with common air. The mercury rose in the tube 42 lines, consequently $\frac{1}{3.4}$ of the air was absorbed. When oxygen gas was

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* *Jour. de Phys.* xxx. 309.

substituted for common air, only $\frac{1}{6.4}$ of its bulk was absorbed[*].

These experiments have been lately repeated upon a larger scale by Mr Rouppe professor of chemistry at Rotterdam, and Dr Van Noorden of the same city. They filled a copper box, which was made air-tight, with red-hot charcoal, allowed it to cool under water, and then introduced it into a glass jar full of air. Seventeen cubic inches of charcoal absorbed, in five hours, 48 cubic inches of air, or $\frac{1}{2.8}$ of its bulk: the same quantity, in 12 hours, absorbed 46 inches of oxygen gas, or $\frac{1}{2.7}$ of its bulk[†]. This absorption is much more considerable than could have been expected from former experiments.

From the experiments of Sennebier, it was concluded that charcoal, when exposed to the atmosphere, absorbs oxygen gas in preference to *azote*, as the other portion of common air is called[‡]. But Rouppe and Van Noorden have shewn, that this happens only when the charcoal is hot: cold charcoal, they found, absorbed atmosperic air unaltered.

How purified.

Common charcoal obtained by burning wood is not quite pure; but the impurities may be carried off by reducing it to powder, washing it repeatedly with pure water, and then drying it by means of a strong heat in close vessels.

Converted by combustion into carbonic acid gas.

3. When charcoal is heated to about 802°[§], or when it is raised to the temperature of about 700° and then plunged into oxygen gas, it takes fire; and, provided

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[*] *Jour. de Phys.* 1783.

[†] *Ann. de Chim.* xxxii. 3.

[‡] *Jour. de Phys.* xxx. 309.

[§] I estimated this temperature, by ascertaining the time at which it has been previously freed from the earths and salts which it generally contains, or if we employ *lamp black*, which is charcoal newly pure, it burns without leaving any residuum. If this combustion be performed in close vessels filled with oxygen gas instead of common air, part of the charcoal and oxygen disappears, and in its room is found a particular gas exactly equal to it in weight. This gas has the properties of an acid, and has been called *carbonic acid gas*. Mr Lavoisier, to whom we are indebted for this discovery, ascertained, by a number of experiments, that carbonic acid gas is composed of about 28 parts of charcoal and 72 of oxygen*.

Composition of charcoal.

Lavoisier supposed pure charcoal to be a simple substance, and for that reason invented the term *carbon* to distinguish it. But other philosophers were of opinion, that charcoal is a compound body, and that it is composed of carbon and oxygen. The truth of this opinion, which, as far as I know, was first maintained by Dr Bancroft†, has been lately established by the experiments of Mr Guyton-Morveau.

Properties of the diamond.

4. The *diamond* is a precious stone, which has been known from the remotest ages. When pure, it is perfectly transparent like crystal, but much more brilliant. Its figure varies considerably; but most commonly it is crystallized in the form of a six-sided prism, terminated by a six-sided pyramid. It is the hardest of all bodies; the best tempered steel makes no impression

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charcoal ceased to burn in an iron plate which had been heated to redness, and measuring the rate of cooling by Sir Isaac Newton's method, to be described hereafter.

* *Mem. Par.* 1781, p. 448.

† *Philosophy of Permanent Colours*, i. 48.

on it; diamond powder can only be obtained by grinding one diamond against another. Its specific gravity is about 3.5. It is a non-conductor of electricity.

Burns,

5. As the diamond is not affected by a considerable heat, it was for many ages considered as incombustible. Sir Isaac Newton, observing that combustibles refract light more powerfully than other bodies, and that the diamond possesses this property in great perfection, suspected it, from that circumstance, to be capable of combustion. This singular conjecture was verified in 1694 by the Florentine academicians, in the presence of Cosmo III. Grand Duke of Tuscany. By means of a burning-glass, they consumed several diamonds. Francis I. Emperor of Germany, afterwards witnessed the destruction of several more in the heat of a furnace. These experiments were repeated by Rouelle, Macquer, and Darcet; who proved that the diamond was not merely evaporated, but actually burnt, and that if air was excluded it underwent no change *.

And forms carbonic acid gas.

No attempt, however, was made to ascertain the product till 1772. Lavoisier, in a Memoir published that year, shewed that when the diamond is burnt, carbonic acid gas is obtained, and that there is a striking analogy between it and charcoal†. In 1785, Guyton-Morveau found that the diamond is combustible when dropped into melted nitre; that it burns without leaving any residuum, and in a manner analogous to charcoal‡. This experiment was repeated with more precision by Mr Tennant in 1797 §. The conclusion which he drew from it was, that when a diamond is burnt, the

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* *Mem. Par.* 1766, 1770, 1771, 1772.

† *Lavoisier*, iii. 160.

‡ *Encyc. Method. Chim.* i. 742.

§ *Phil. Trans.* 1797, p. 123.

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whole of the product is carbonic acid gas; that a given weight of diamond yields just as much carbonic acid gas as the same weight of charcoal; and that diamond and charcoal are both composed of the very same substance.

Differs from charcoal.

6. This conclusion, that diamond is nothing else but charcoal, was directly contrary to what one would have expected from comparing the two substances together. Their colour, hardness, specific gravity, and electrical properties, are exceedingly different; nor do they resemble each other more nearly in their combustibility. Charcoal takes fire at a red heat, and when once kindled in oxygen gas continues to burn till it be wholly consumed. The diamond, before it can be burnt, must be exposed to the sun's rays in the focus of a large burning glass, or to a heat not under 5000°[*]: even then it consumes but slowly, and ceases to burn the instant the action of the burning glass is withdrawn. Its surface assumes a black colour like charcoal: this crust is soon wasted, and another is formed in its place. It was in this manner that a diamond weighing 3.089 gr. troy gradually wasted away completely when exposed by Morveau for 1 hour and 40 minutes in the focus of the celebrated burning-glass of Tschirnhausen, while a thermometer exposed to the sun stood at 104°[†].

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[*] Sir George M'Kenzie, however, found that diamonds will burn in a muffle when heated no higher than 14° or 15° Wedgewood; which must be considerably lower than 5000° Fahrenheit. *Nicholson's Journal*, iv. 104. As his experiment was made on purpose to ascertain the precise temperature at which the diamond burns, it is more to be depended on than the calculations of Morveau, who does not inform us on what data he goes.

[†] *Ann. de Chim.* xxxi. 90.

Morveau found, that one part of diamond during its combustion combines with 4.592 parts of oxygen, and the carbonic acid gas formed amounts to 5.592 parts. Consequently carbonic acid gas is composed of one part of diamond and 4.592 of oxygen; or, which is the same thing, 100 parts of carbonic acid gas are composed of

17.88 Diamond,
82.12 Oxygen.
100.00*

But Lavoisier ascertained, that one part of charcoal, when burnt, combines with 2.5714 parts of oxygen, and forms 3.5714 parts of carbonic acid gas. Consequently 100 parts of carbonic acid gas are composed of

28 Charcoal,
72 Oxygen.
100

But 100 parts of carbonic acid gas are also composed of 17.88 diamond and 82.12 oxygen. We have therefore this equation:

$$\overset{\text{Diamond.}}{17.88} + \overset{\text{Oxygen.}}{82.12} = \overset{\text{Charcoal.}}{28} + \overset{\text{Oxygen.}}{72}.$$

Consequently, subtracting 72 parts of oxygen from both sides of the equation, we have

$$\overset{\text{Diamond.}}{17.88} + \overset{\text{Oxygen.}}{10.12} = 28 \text{ charcoal.}$$

That is to say, 28 parts of charcoal are composed of 17.88 diamond and 10.12 oxygen. Of course, 100 parts of charcoal are composed of

63.85 Diamond,
36.15 Oxygen.
100.00

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* *Ann. de Chim.* xxxi. 99.

Diamond, pure carbon.

Thus we see why diamond and charcoal possess different properties: the one is a simple substance; the other is a compound of the diamond and oxygen, or it is what the French chemists call an *oxide of diamond*. The diamond, then, is that substance in a state of purity to which Lavoisier and his associates gave the name of *carbon*; charcoal is not *carbon*, as they supposed, but the *oxide of carbon*.

Carburets.

6. Carbon unites with a number of bodies, and forms with them compounds, which have received the name of *carburets*; but the order of its affinities for these bodies has not been ascertained. Let us examine the compounds which it forms with sulphur and phosphorus, the two substances which have been already described.

Carburet of sulphur.

7. Till lately it was supposed that sulphur does not combine with carbon: but Messrs Desormes and Clement, two French chemists, who have paid particular attention to the properties of carbon, have lately announced a method of combining them. Their method is as follows: Fill a porcelain tube with charcoal, and make it pass through a furnace in such a way that one end shall be considerably elevated above the other. To the under end lute a wide glass tube of such a length and shape that its end can be plunged to the bottom of a bottle of water. To the elevated end lute another glass tube filled with small bits of sulphur, and secured at the further end so that the sulphur may be pushed forward by means of a wire, without allowing the inside of the tube to communicate with the external air. Heat the porcelain tube, and consequently the charcoal which it contains, to redness, and continue the heat till air-bubbles cease to come from the charcoal; then push the

sulphur slowly, and piece after piece, into the porcelain tube. A substance passes through the glass tube, and condenses under the water of the bottle into a liquid. This liquid is *carburet of ſulphur*.

This liquid is transparent and colourless when pure, but very frequently it has a greenish yellow tinge. Its taste is cooling and pungent, and its odour strong and peculiar. Its specific gravity is 1.3. It does not mix with water. When put into the receiver of an air pump, and the air exhausted, it rises in bubbles through the water, and assumes the form of a gas. The same change takes place when it is introduced to the top of a barometer tube; but it is again condensed into a liquid when the tube is immersed under mercury.

This compound burns easily like spirit of wine and many other liquids. During the combustion it emits a sulphureous odour; sulphur is deposited, and charcoal remains behind. When a little of it is put into a bottle filled with oxygen gas, it gradually mixes with the oxygen, and assumes the gaseous form. If a burning taper be applied to the mouth of the bottle, the mixture burns instantaneously, and with an explosion so violent as to endanger the vessel. It assumes the gaseous form in the same way when placed in contact with air. This mixture does not detonate when kindled, but burns quietly.

Carburet of sulphur dissolves phosphorus readily. It dissolves likewise a small portion of sulphur; but has no action whatever on charcoal *.

Phosphuret of carbon.

8. Phosphorus is capable of combining with carbon, or rather with charcoal. This compound, which has received the name of *phosphuret of carbon*, was first ex-

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* *Ann. de Chim.* 42. 136.

amined by Mr Proust, the celebrated Professor of chemistry in Spain. It is the red substance which remains behind when new-made phosphorus is strained through shamoy leather. In order to separate from it a small quantity of phosphorus which it contains in excess, it should be put into a retort and exposed for some time to a moderate heat. What remains behind in the retort is the pure phosphuret of carbon. It is a light, flocky powder, of a lively orange red, without taste or smell. When heated in the open air it burns rapidly, and a quantity of charcoal remains behind. When the retort in which it is formed is heated red hot, the phosphorus comes over, and the charcoal remains behind *.

SECT. IV.

OF HYDROGEN.

The fourth and last of the simple combustibles to which we now proceed, may be procured in the following manner:

Into a retort having an opening at A †, (fig. 7.) put one part of iron filings; then shut the opening A with a cork, through which a hole has been previously drilled by means of a round file, and the bent funnel B passed through it. Care must be taken that the funnel and cork fit the retort so as to be air tight. Plunge the beak of the retort C under water; then pour through

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* *Ann. de Chim.* xxxiv. 44.

† Such retorts are called *tubulated* by chemists.

the bent funnel two parts of sulphuric acid previously diluted with four times its bulk of water. Immediately the mixture begins to boil or *effervesce* with violence, and air-bubbles rush abundantly from the beak of the retort. Allow them to escape for a little, till you suppose that the common air which previously filled the retort has been displaced by the new generated air. Then place an inverted jar on the pneumatic shelf over the beak of the retort. The bubbles rush in abundantly and soon fill the jar. The gas obtained by this process is called *hydrogen gas.* It was formerly called *inflammable air*, and by some chemists *phlogiston.*

It was obtained by Dr Mayow and by Dr Hales from various substances, and had been known long before in mines under the name of the *fire damp.* But Mr Cavendish ought to be considered as its real discoverer; since it was he who first examined it, who pointed out the difference between it and atmospheric air, and who ascertained the greatest number of its properties *. They were afterwards more fully investigated by Priestley, Scheele, Sennebier, and Volta.

Its properties.

1. Hydrogen gas, like *air*, is invisible and elastic, and capable of indefinite compression and dilatation.

Its specific gravity differs according to its purity. Kirwan found it 0.00010 †; Lavoisier 0.000094 ‡, or about 12 times lighter than common air.

2. All burning substances are immediately extinguished by being plunged into this gas. It is incapable therefore of supporting combustion.

3. Small animals, when they are obliged to breathe

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* *Phil. Trans.* lvi. 141.

† *On Phlogiston*, Sect. i.

‡ Lavoisier's *Chemistry*, Appendix.

it, die; but large animals resist its action longer. Scheele found that he could breathe it for some time without much inconvenience *; but Fontana, who repeated the experiment, affirmed that this was owing to the quantity of common air contained in the lungs when he began to breathe; for on expiring as strongly as possible before drawing in the hydrogen gas, he could only make three respirations, and even these three produced extreme feebleness and oppression about the breast †.

The ingenious Mr Davy, Professor of chemistry in the Royal institution, to whom we are indebted for many curious and important, but rather hazardous experiments on respiration, made chiefly upon himself, after a complete voluntary exhaustion of his lungs, found great difficulty in breathing this gas for so long as half a minute. It produced uneasy feelings in the chest, momentary loss of muscular power, and sometimes a transient giddiness †. But when he did not

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* Scheele *on Fire*, p. 60.

† *Jour. de Phys.* xv. 99.—Pilatre de Rozier publicly verefied the assertions of Scheele. He breathed hydrogen gas six or seven times from a bladder without inconvenience. To demonstrate that it was really hydrogen gas which he was breathing, he made a strong inspiration, and expired the air slowly through a long tube. On bringing a lighted taper to the end of the tube, the gas took fire, and continued to burn for some time. It was objected to him, that the gas which he breathed was diluted with common air. To shew that this was not the case, he mixed together one part of common air and nine parts of hydrogen gas, and having drawn the mixture into his lungs, he threw it out the same way. On applying a taper to the tube, the whole of the gas exploded in his mouth, and almost stunned him. At first he thought that the whole of his teeth had been driven out; but fortunately he received no injury whatever. See *Jour. de Phys.* 28. 425.

‡ Davy's *Researches*, p. 400.

previously empty his lungs, he was able to breathe it for about a minute without much inconvenience *. When much diluted with common air, it may be breathed without injury.

Combustible.

4. If a phial be filled with hydrogen gas, and a lighted candle be brought to its mouth, the gas will take fire, and burn gradually till it is all consumed. If the hydrogen gas be pure, the flame is of a white colour; but if the gas holds any substance in solution, which is often the case, the flame is tinged of different colours, according to the substance. It is most usually reddish, because the gas holds in solution a little charcoal. A red hot iron likewise sets fire to hydrogen gas. From my experiments it follows, that the temperature at which the gas takes fire is about 1000°.

Explodes with oxygen gas, and forms water.

If pure oxygen and hydrogen gas be mixed together, they remain unaltered; but if a lighted taper be brought into contact with them, or an electric spark be made to pass through them, they burn with astonishing rapidity, and produce a violent explosion. If these two gases be mixed in the proportion of one part in bulk of oxygen gas and 2.527 parts of hydrogen gas, or, more accurately, 85 parts by weight of oxygen gas and 15 of hydrogen gas, they explode over water without leaving any visible residuum; the vessel in which they were contained (provided the gases were pure) being completely filled with water. But if the explosion be made in a close vessel, there is always found instead of them a quantity of water exactly equal to them in weight. This water must be composed of these two gases; for it did not previously exist in the vessel, and no other

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* Davy's *Researches*, p. 466.

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substance besides the gases were introduced. Water then is composed of oxygen and hydrogen; and the combustion of hydrogen is nothing else but the act of its combination with oxygen [*].

When two parts (in bulk) of hydrogen gas are mixed with ſix parts of common air, the mixture explodes with equal violence; and after the explosion, the bulk of the mixture is reduced to five parts. The whole of the hydrogen gas is consumed, and likewise all that part of the common air which consists of oxygen gas, and there is formed a quantity of water equal in weight to these two bodies. This experiment is often employed to ascertain the purity of hydrogen gas. Common air and the hydrogen gas to be examined are mixed in certain proportions in a glass tube, graduated and close at one end; they are then fired by an electric spark. The purity of the gas is proportional to the diminution of bulk. Thus, when the bulk of a mixture of two parts of hydrogen gas and ſix parts of air is diminished after the explosion to five parts, the hydrogen gas may be considered as pure; if only to ſix, it contains some foreign ingredients; and so on. This method of detecting the purity of hydrogen gas was first employed by Berthollet. Volta, indeed, had employed it before him; but for a different purpose [*].

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[*] The history of this great discovery, and the objections which have been made to it, will be given in the Section which treats of WATER, where they will be better understood than they can be at present. It ought never to be forgotten, that Newton had long before, with a sagacity almost greater than human, conjectured, from the great refracting power of water, that it *contains a combustible substance.*

[†] Crell's *Annals* 1785, ii. 287.

4. It had been supposed, in consequence of the experiments of Dr Priestley and several other philosophers, that when hydrogen gas is allowed to remain in contact with water, it is gradually decomposed, and converted into another gas; but Mr de Morveau *, Mr Hassenfratz †, and Mr Libes ‡, have shewn, that it undergoes no change, provided sufficient care be taken to exclude every other gas.

Hydrogen gas is not senſibly absorbed by water, though left for some time in contact with it. But by artificial pressure water may be made to absorb about the third part of its bulk of that gas. The taste of the water is not sensibly altered. Mr Paul, who first formed this compound, informs us, that it is useful in inflammatory fevers and in nervous complaints; but it is injurious in dropsy §.

5. Hydrogen gas dissolves sulphur, phosphorus, and carbon. The compounds are called *sulphureted, phosphureted*, and *carbureted hydrogen gas*.

Sulphureted hydrogen gas,

I. Sulphureted hydrogen gas may be obtained by melting with a burning glass sulphur inclosed in a jarful of hydrogen gas, or by making hydrogen gas pass through melted sulphur. The hydrogen gas dissolves part of the sulphur, and is converted into sulphureted hydrogen gas. But this gas is more usually obtained by the following process.

How obtained.

Melt together, in a crucible, equal parts of iron filings and sulphur; the product is a black brittle mass. Reduce this to powder, and put it, with a little water,

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* *Encyc. Method. Chim.* i. 754.

† *Ann. de Chim.* i. 192.

‡ *Jour. de Phys.* xxxvi. 412.

§ *Phil. Mag.* xv. 93.

into a glass vessel with two mouths. Lute a crooked glass tube to one of these mouths, and let the other extremity of it pass under a glass jar full of water. Pour muriatic acid through the other mouth, and then immediately close it up. Sulphureted hydrogen gas is disengaged abundantly, and fills the glass jar.

This gas was first examined by Rouelle junior in 1773 *. But Scheele and Bergman were the chemists who first published an account of its properties. Scheele, in his treatise *on Fire*, in 1777 †, and Bergman, in his Dissertation *on Artificial Hot Mineral Waters*, in 1778 ‡. Mr Kirwan published a very copious and ingenious set of experiments on it in 1785; and in 1794, Berthollet, with his usual skill, still farther developed its properties. It was long known by the name of *hepatic gas*, because the substances from which it was first obtained were at that time called *hepars*, or *livers of sulphur*.

Its properties.

The specific gravity of sulphureted hydrogen gas is 0.00135 §; it is to common air as 1106 to 1000.

It has a very fetid odour, precisely similar to that emitted by rotten eggs, which indeed is owing to the emission of the very same gas.

It is not more respirable than hydrogen gas. When set on fire, in contact with oxygen gas, it burns with a light blue flame, without exploding, and at the ſame time a quantity of sulphur is deposited. The combustion of this gas, then, is merely the union of its hydrogen, and perhaps part of its sulphur, with oxygen.

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* Fourcroy *Connais. Chim.* i. 32.

† P. 186. English trans.

‡ Bergman, *Opuscula*, i. 233.

§ Kirwan *on Phlogiston*, Sect. i.

This gas is absorbed readily by water; but as it possesses the properties of an acid, a detailed account of its properties belongs to a different part of this Work*. We learn, from the experiments of Thenard, that it is composed of

70.857	Sulphur,
29.143	Hydrogen †.
100.000	

This gas has the property of dissolving a small quantity of phosphorus. Nothing more is necessary than to allow bits of phosphorus to remain for some hours in glass jars filled with the gas. When common air is admitted to this compound, a very voluminous bluish flame is produced, owing evidently to the combustion of the dissolved phosphorus. When the hands or a sponge are plunged into it, they continue luminous in the air for some time after ‡.

Phosphorized hydrogen gas.

II. When bits of phosphorus are kept for some hours in hydrogen gas, part of the phosphorus is dissolved. This compound gas, to which Fourcroy and Vauquelin, the discoverers of it, have given the name of *phosphorized hydrogen gas*, has a slight smell of garlic. When bubbles of it are made to pass into oxygen gas, a very brilliant bluish flame is produced, which pervades the whole vessel of oxygen gas. It is obvious that this flame is the consequence of the combustion of the dissolved phosphorus §.

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* Trommsdorf has given it the name of *hydrothionic acid*.

† *Ann. de Chim.* xxxii. 267.

‡ Fourcroy and Vauquelin, *Ibid.* xxi. 206.

§ *Ibid.* xxi. 202.

Phosphureted hydrogen gas.

When phosphorus is introduced into a glass jar of hydrogen gas standing over mercury, and then melted by means of a burning glass, the hydrogen gas dissolves a much greater proportion of it. The new compound thus formed has received the name of *phosphureted hydrogen gas*. It was discovered in 1783 by Mr Gengembre[*]; and in 1784 by Mr Kirwan, before he became acquainted with the experiments of Gengembre. But for the fullest investigation of its properties, we are indebted to Mr Raymond, who published a dissertation on it in 1791[†], and another in 1800[‡]. These philosophers obtained the gas by a different process, which shall be afterwards described: but in whatever manner it is prepared, its properties are always the same.

Its properties.

It has a very fetid odour, exactly similar to the smell of putrid fish. When it comes into contact with common air, it burns with great rapidity; and if mixed with that air, it detonates violently. Oxygen gas produces a still more rapid and brilliant combustion than common air. When bubbles of it are made to pass up through water, they explode in succession as they reach the surface of the liquid; a beautiful coronet of white smoke is formed, which rises slowly to the ceiling. This gas is the most combustible substance known. It is obvious, that its combustion is merely the combination of its phosphorus and its hydrogen with the oxygen of the atmosphere; the products, of course, are phosphoric acid and water. These two substances

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[*] *Mem Sçav. Etrang.* x.

[†] *Ann. de Chim.* x. 19.

[‡] *Ibid.* xxxv. 225

mixed, or rather combined, constitute the coronet of white smoke.

Pure water, when agitated in contact with this gas, dissolves at the temperature of between 50° and 60° about the fourth part of its bulk of it. The solution is of a colour not unlike that of roll sulphur; it has a very bitter and disagreeable taste, and a strong unpleasant odour. When heated nearly to boiling, the whole of the phosphureted hydrogen gas is driven off unchanged, and the water remains behind in a state of purity. When exposed to the air, the phosphorus is gradually deposited in the state of oxide; the hydrogen gas makes its escape; and at last nothing remains but pure water*.

Carbureted hydrogen gas.

III. Carbureted hydrogen gas rises spontaneously from the bottom of stagnant waters in hot weather, and may be easily collected in considerable quantity. It may be formed, too, by exposing charcoal in hydrogen gas to the rays of the sun†, or by distilling wet charcoal in a retort. It is formed also in abundance, when spirit of wine or ether is made to pass through red hot porcelain tubes‡; and in many other processes to be afterwards described. This gas was formerly called *heavy inflammable air*.

It was first examined with attention by Volta. Dr Priestley soon after made experiments on different kinds of it; but its composition seems to have been first pointed out by Lavoisier; and for the most accurate

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* Raymond, *Ann de Chim.* xxxv. 233.

† Fourcroy, *Connaiss.* i. 181.

‡ Dutch chemists, *Ann. de Chim.* xxi 48.

analysis of it which has hitherto appeared, we are indebted to Mr Cruickshank of Woolwich*.

It differs considerably in its component parts, and of course in its properties, according to the process by which it is obtained. Like common air, it is invisible and elastic; like hydrogen gas, it is inflammable, and explodes when fired along with oxygen gas or common air; but the product is a mixture of water and carbonic acid. When exploded in a tube with these gases, the residuum occupies more room than the original mixture.

Different species of.

Carbureted hydrogen gas, obtained from stagnant water, from ether, from camphor, or from vegetable substances, contains most carbon. Its specific gravity is 0.000804. It is to common air as 155 to 235, or nearly as 2 to 3. It contains one part by weight of hydrogen gas, holding 5.5 parts of carbon in solution. One hundred parts of it in its usual state contain, according to Mr Cruickshank,

52.35	Carbon,
9.60	Hydrogen,
38.05	Water in the state of vapour.
100.00†	

That obtained by distilling wet charcoal contains the least carbon, and of course is the lightest. Its specific gravity is 0.000554. It is to common air as 14.5 to 31, or nearly as 1 : 2. It contains one part (by weight) of hydrogen gas, holding in solution three parts of carbon. One hundred parts of it are composed of

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* Nicholson's *Journal*, v. 1.

† *Ibid.* v. 8

28	Carbon,
9	Hydrogen,
63	Water.
100	

The specific gravity of the carbureted hydrogen gas obtained from ether is 0.000787. It is composed of

45	Carbon,
15	Hydrogen,
40	Water.
100	

The specific gravity of the gas obtained from spirit of wine is 0.00063. It is composed of

44.1	Carbon,
11.8	Hydrogen,
44.1	Water.
100.0	

These are the only species of carbureted hydrogen gas at present known, one only excepted, which is obtained from alcohol, by a peculiar process to be hereafter described.

The affinity of hydrogen gas for these three combustibles is as follows:

Sulphur,
Carbon,
Phosphorus*.

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* Sulphur decomposes carbureted hydrogen gas; therefore its affinity is greater than that of carbon. The Dutch chemists melted phosphorus in carbureted hydrogen gas, but no change was produced; therefore the affinity of phosphorus is inferior to that of carbon.

Austin's theory of the composition of carbon

Dr Austin found, that by repeatedly passing electric explosions through a small quantity of carbureted hydrogen gas, it was permanently dilated to more than twice its original bulk. He rightly concluded, that this remarkable expansion could only be owing to the evolution of hydrogen gas. On burning air thus expanded, he found that it required a greater quantity of oxygen than the same quantity of gas not dilated by electricity: An addition therefore had been made to the combustible matter; for the quantity of oxygen necessary to complete the combustion of any body is always proportional to the quantity of that body. He concluded from these experiments, that he had decomposed the carbon which had been dissolved in the hydrogen gas; and that carbon was composed of hydrogen and azote*, some of which was always found in the vessel after the dilated gas had been burnt by means of oxygen †. If this conclusion be fairly drawn, we must expunge *carbon* from the list of simple substances, and henceforth consider it as a compound.

Refuted.

There was one circumstance which ought to have prevented Dr Austin from drawing this conclusion, at least till warranted by more decisive experiments. The

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* See next Section.—His theory was, that carbureted hydrogen gas was composed of hydrogen and azote, and carbon of azote and carbureted hydrogen gas; which comes nearly to the same thing with regard to the elements of carbon. It is singular enough, that though Dr Austin would not allow the presence of carbon in carbureted hydrogen gas, he actually decomposed it by melting sulphur in it: the sulphur combined with the hydrogen gas, and a quantity of charcoal was precipitated. This experiment he relates without making any remarks upon it, and seems indeed not to have paid any attention to it.

† *Phil. Trans.* lxxx. 51.

Chap. II.

quantity of combustible matter had been increased. Now, if the expansion of the carbureted hydrogen gas were owing merely to the decomposition of carbon, no such increase ought to take place, but rather the contrary; for the carbon, which is itself a combustible substance, is resolved into two ingredients, hydrogen and azote, only the first of which burnt on the addition of oxygen and the application of heat. Dr Austin's experiments have been lately repeated by Mr William Henry with a great deal of accuracy*. He found, that the dilatation which Dr Austin describes actually took place, but that it could not be carried beyond a certain degree, a little more than twice the original bulk of the gas. Upon burning separately by means of oxygen, two equal portions of carbureted hydrogen gas, one of which had been expanded by electricity to double its original bulk, the other not, he found that each of them produced precisely the same quantity of *carbonic acid gas*. Both therefore contained the same quantity of carbon; consequently no carbon had been decompounded by the electric shocks.

Mr Henry then suspected that the dilatation was owing to the water which every gas contains in a larger or smaller quantity. To ascertain this, he endeavoured to deprive the carbureted hydrogen gas of as much water as possible, by making it pass over very dry potass, which attracts water with avidity. Gas treated in this manner could only be expanded one-sixth of its bulk; but on admitting a drop or two of water, the expansion went on as usual. The substance decompound-

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* *Phil. Trans.* 1797, Part ii.

ed by the electricity, then, was not the carbon, but the water in the carbureted hydrogen gas. Nor is it difficult to see in what manner this decomposition is effected. Carbon at a high temperature has a greater affinity for oxygen than hydrogen has; for if the steam of water be made to pass over red hot charcoal, it is decomposed, and carbonic acid and hydrogen gas are formed. The electric explosion supplies the proper temperature; the carbon unites with the oxygen of the water, and forms carbonic acid; and the hydrogen, thus set at liberty, occasions the dilatation. Carbonic acid gas is absorbed with avidity by water: and when water was admitted into 709 measures of gas thus dilated, 100 measures were absorbed; a proof that carbonic acid gas was actually present. As to the azote which Dr Austin found in his dilated gas, it evidently proceeded from the admission of some atmospheric air, about 78 parts of which in the 100 consist of this gas: for Dr Austin's gas had stood long over water; and Drs Priestley and Higgins have shewn that air in such a situation always becomes impregnated with azote*.

6. The affinities of hydrogen have not yet been ascertained; but perhaps they are as follows:

Oxygen,
Carbon,
Azote.

Hydrogen gas absorbed by charcoal.

7. Charcoal has the property of absorbing hydrogen gas, but it absorbs a smaller proportion of it than of any other gas hitherto tried. Morozzo found, that a

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* The increase of the combustible matter in Dr Austin's experiment was doubtless owing to the oxidation of a part of the mercury at the expence of the water.

bit of charcoal, 12 lines long and 8 in diameter, extinguished in mercury, and then plunged into a tube 144 lines long and 12 in diameter, and filled with hydrogen gas, absorbed $\frac{1}{5.5}$ of the whole. Rouppe and Van Noorden found, that new-made charcoal, allowed to cool without being exposed to the air, when plunged into hydrogen gas, absorbed about half its bulk of it. When charcoal, thus impregnated with hydrogen gas, is exposed to common air, the oxygen of the air is absorbed, combines with the hydrogen, and forms water. The same phenomena present themselves when oxygen gas is employed instead of common air *.

Properties of the simple combustibles.

SUCH are the properties of all the simple combustibles, if we except the metals. One of them, namely carbon, exists only in a solid state, and cannot be converted by any processes at present known either into a liquid or a gas. Sulphur and phosphorus are usually solid; but a moderate heat melts them, and an increase of temperature makes them boil and converts them into vapour. Hydrogen, in a separate state, can only be obtained under the form of a gas.

Combine with oxygen.

All of them combine with oxygen, but at different temperatures; and during their combination with it, provided the temperature be sufficiently elevated, *combustion*, or the emission of a vast quantity of heat and light, takes place. Phosphorus for combustion requires the temperature of 148°, sulphur the temperature of 560°, hydrogen and charcoal a red heat, and the diamond a still higher temperature. An enquiry into the

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* *Ann. de Chim.* xxxii. 18.

Book I. Division I.

cause of this difference, and into the source of the heat and light, or of the *fire*, which makes its appearance during combustion, constitutes one of the most interesting parts of chemistry. But it will be improper to enter upon it, till we have made ourselves acquainted with the properties of the remaining simple bodies; because they will furnish us with a number of additional facts, which will considerably facilitate any subsequent investigation of these important questions.

It deserves particular attention, that all the simple combustibles, except hydrogen, are capable of combining with three different doses of oxygen, and of forming with it three compounds, each possessed of peculiar properties.

Compounds of sulphur and oxygen,

1. Sulphur, when kept long in a state of fusion, combines with a small dose of oxygen, and is converted into *oxide of sulphur*. When heated to 560° in the open air, it burns with a blue flame, combines with oxygen, and forms an acid which has a peculiarly suffocating odour, and is called *sulphurous acid*. When plunged burning into oxygen gas, or when mixed with nitre and set on fire, it combines with a maximum of oxygen, and forms an acid without smell called *sulphuric acid*. Thus sulphur and oxygen combined together form,

1. Oxide of sulphur,
2. Sulphurous acid,
3. Sulphuric acid.

Phosphorus and oxygen,

2. Phosphorus under water gradually acquires a brown colour, owing, it is supposed, to its combining with a little oxygen. This compound is called *oxide of phosphorus*. When phosphorus is left exposed to the open air, it gradually combines with oxygen, and is converted into an acid liquid called *phosphorous acid*.

When set on fire, it combines with a maximum of oxygen, and is converted into white flakes, destitute of smell, called *phosphoric acid.* Thus phosphorus and oxygen combined together form,

1. Oxide of phosphorus,
2. Phosphorous acid,
3. Phosphoric acid.

Carbon and oxygen,

3. Carbon likewise combines with three doses of oxygen; though the compounds cannot be all formed from the diamond, on account of its hardness. *Charcoal*, exposed to the strong heat of a forge, constitutes the compound containing carbon combined with a minimum of oxygen. It ought, in strict propriety, to be called *carbonous oxide.* By applying a red heat to a mixture of iron filings and chalk, a gas is obtained, which is composed of *carbon* combined with a greater dose of oxygen than that which exists in charcoal. This gas is called *carbonic oxide.* Its properties will be examined in a subsequent part of this Work. When charcoal is set on fire, it combines with a maximum of oxygen, and forms a gas known by the name of *carbonic acid.* Thus carbon and oxygen combined together form,

1. Carbonous oxide,
2. Carbonic oxide,
3. Carbonic acid.

Hydrogen and oxygen.

The first two simple combustibles form with oxygen one oxide and two acids. The third forms with it two oxides and one acid. Hydrogen, the fourth of them, combines only in one proportion, and forms water.

It deserves attention, that the product of the combustion of all the simple combustibles, except hydrogen, is an acid. The oxides are formed without combustion, and they are themselves combustible.

Combination of the combustibles with each other.

All the simple combustibles are capable of combining with each other. Chemists have agreed to give to all such combinations a name ending in *uret*, and derived from that ingredient which is supposed to characterise the compound. Thus we have *sulphuret of phosphorus*, of *carbon*, and of *hydrogen ;* but the last compound being gaseous, is usually denominated *sulphureted hydrogen gas*. We have likewise *phosphuret of sulphur*, of *carbon*, and of *hydrogen*, or phosphureted hydrogen gas. We have also various species of *carbureted hydrogen gas*. All these compounds retain their combustibility.

Chap. III.

CHAP. III.

OF SIMPLE INCOMBUSTIBLES.

Number.

THE third class of simple confinable bodies comprehends under it only two substances; namely, *azote* and *muriatic acid.* There are indeed twelve other incombustible bodies not hitherto decompounded; but all of them differing so essentially from azote and muriatic acid in their properties, that it is necessary to consider them apart: and at present analogy leads us to place them among the compounds. Even muriatic acid, tho' its resemblance to azote is striking, differs from it in so many particulars, that I dare not venture to separate it from the class of acids under which it has been hitherto arranged.

SECT. I.

OF AZOTE.

Method of procuring azotic gas.

Azote may be procured by the following processes: If a quantity of iron filings and sulphur, mixed together, and moistened with water, be put into a glass vessel full of air, it will absorb all the oxygen in the course of a few days; but a considerable residuum of air will still remain incapable of any farther diminution. This residuum has obtained the appellation of *azotic gas*. There are other methods of obtaining it more speedily. If phosphorus, for instance, be substituted for the iron-filings and sulphur, the absorption is completed in less than 24 hours. The following method, first pointed out by Berthollet, furnishes very pure azotic gas, if the proper precautions be attended to. Very much diluted *aquafortis*, or *nitrous acid* as it is called in chemistry, is poured upon a piece of muscular flesh, and a heat of about 100° applied. A considerable quantity of azotic gas is emitted, which may be received in proper vessels.

This gas was discovered in 1772 by Dr Rutherford, now professor of botany in the university of Edinburgh *.

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* See his thesis *De Aere Mephitico*, published in 1772.—" Sed aer salubris et purus respiratione animali non modo ex parte fit mephiticus sed et *aliam indolis suæ mutationem inde patitur.* Postquam enim omnis aer mephiticus (*carbonic acid gas*) ex eo, ope lixivii caustici secretus et abductus ſuerit, *qui tamen restat* nullo modo salubrior inde evadit; nam quamvis nullam ex aqua calcis præcipitationem faciat haud minus quam antea *et flammam et vitam extinguit.* Page 17.

Scheele procured it by the first mentioned process as early as 1776, and proved that it was a distinct fluid.

Exists in the atmosphere.

1. The air of the atmosphere contains about 0.78 parts (in bulk) of azotic gas; almost all the rest of it is oxygen gas. Mr Lavoisier was the first philosopher who published this analysis, and who made azotic gas known as a component part of air. His experiments were published in 1774, or perhaps rather 1775. Scheele undoubtedly was acquainted as early with the composition of air; but his Treatise on Fire, in which that analysis is contained, was not published till 1777.

Its properties.

2. Mr Kirwan examined the specific gravity of azotic gas obtained by Scheele's process; it was 0.00120: it is therefore somewhat lighter than atmospheric air; it is to atmospheric air as 985 to 1000 *. According to the experiments of Lavoisier, its specific gravity is only 0.00115, or it is to common air as 942.6 : 1000†.

3. This gas is invisible and elastic like common air; and like it too, capable of indefinite condensation and dilatation. It is exceedingly noxious to animals; if obliged to respire it, they drop down dead almost in-

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"Aer qui per carbones ignitos folle adactus fuit, atque deinde ab omni aere mephitico (*carbonic acid gas*) expurgatus, malignus tamen adhuc reperitur et omnino similis est ei qui respiratione inquinatur. Immo ab experimentis patet, hanc solam esse aeris mutationem quæ inflammationi adscribi potest. Si enim accenditur materies quælibet quæ ex phlogisto et basi fixa atque simplici constat, *aer inde natus ne minimam aeris mephitici quantitatem in se continere videtur*. Sic aer in quo sulphur aut phosphorus urinæ combustus fuit, licet maxime malignus, calcem tamen ex aqua minime præcipitat. Interdum quidem si ex phosphoro natus fuerit, nubeculam aquæ calcis inducit sed tenuissimam, nec aeri mephitico attribuendam, sed potius acido illi quod in phosphoro inest, et quod, ut experimenta docuerunt, hoc singulari dote pollet." Page 19.

* *On Phlogiston*, § 1.

† *Ibid* p. 57.

stantly*. No combustible will burn in it. Hence the reason why a candle is extinguished in atmospherical air as soon as the oxygen near it is consumed. Mr Goettling, indeed, published, in 1794, that phosphorus shone, and was converted into phosphoric acid, in pure azotic gas. Were this the case, it would not be true that no combustible will burn in this gas; for the conversion of phosphorus into an acid, and even its ſhining, is an actual though ſlow combustion. Mr Goettling's experiments were soon after repeated by Drs Scherer and Jaeger, who found, that phosphorus does not ſhine in azotic gas when it is perfectly pure; and that therefore the gas on which Mr Goettling's experiments were made had contained a mixture of oxygen gas, owing principally to its having been confined only by water. These results were afterwards confirmed by Professor Lampadius and Professor Hildebrandt. It is therefore proved beyond a doubt, that phosphorus does not burn in azotic gas; and that whenever it appears to do so there is always some oxygen gas present†.

Combines with oxygen.

4. Azotic gas is capable of combining with oxygen. Take a glass tube, the diameter of which is about the sixth part of an inch; shut one of its ends with a cork, through the middle of which passes a small wire with a ball of metal at each end. Fill the tube with mercury, and then plunge its open end into a bason of that fluid. Throw up into the tube as much of a mixture, composed of 13 parts of azotic and 87 parts of oxygen gas,

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[*] Hence the name *azote*, given it by the French chemists, which signifies "destructive to life," from *α* and *ζωη*.

[†] Nicholson's *Journal*, ii. 8.

as will fill 3 inches. Through this gas make, by means of the wire in the cork, a number of electric explosions pass. The volume of gas gradually diminishes, and in its place there is found a quantity of *nitric acid*. This acid, therefore, is composed of azote and oxygen : and these two substances are capable of combining, or, which is the same thing, azotic gas is capable of combustion in the temperature produced by electricity, which we know to be high. The combination of azotic gas with oxygen, and the nature of the product, was discovered by Mr Cavendish, and communicated to the Royal Society on the 2d of June 1785*.

Product nitric acid.

Sulphureted azotic gas.

5. When sulphur is melted in azotic gas, part of it is dissolved, and *sulphureted azotic gas* formed. This gas has a fetid odour. Its properties are still unknown†. It has been lately discovered by Gimbernat, in the waters of Aix-la-Chapelle ‡.

Phosphureted azotic gas.

Phosphorus plunged into azotic gas is dissolved in a small proportion. Its bulk is encreased about $\frac{1}{40}$ §, and *phosphureted azotic gas* is the result. When this gas is mixed with oxygen gas, it becomes luminous, in consequence of the combustion of the dissolved phosphorus. The combustion is most rapid when bubbles of phosphureted azotic gas are let up into a jar full of oxygen gas. When phosphureted oxygen gas, and phosphureted azotic gas, are mixed together, no light is produced, even at the temperature of 82°¶.

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* This illustrious chemist carried the discovery at once to a state of perfection. His estimation of the proportions of azote and oxygen, which constitute nitric acid, have been ascertained to be much more precise than the subsequent estimation of Lavoisier.

† Fourcroy, i. 200. ‡ *Jour. de Chim.* ii. 114. § Berthollet.

¶ Fourcroy and Vauquelin, *Ann. de Chim.* xxi. 199.

Azotic gas dissolves also a little carbon: for azotic gas obtained from animal substances, by Berthollet's process, when confined long in jars, depoſites on the sides of them a black matter, which has the properties of charcoal *.

Azote a component part of *ammonia.*

When mixed with hydrogen gas, it undergoes no change. It may, however, be combined with hydrogen, by processes which will be described hereafter. The compound formed is known by the name of *ammonia* or *volatile alkali.*

Attempts to decompose azote.

6. The affinities of azote are still unknown. It has never yet been decompounded, and must therefore, in the present state of our knowledge, be considered as a simple substance. Dr Priestley, who obtained azotic gas at a very early period of his experiments, considered it as a compound of oxygen gas and phlogiston, and for that reason gave it the name of *phlogisticated air.* According to the theory of Stahl, which was then universally prevalent, he considered combustion as merely the separation of phlogiston from the burning body. To this theory he made the following addition: Phlogiston is separated during combustion by means of chemical affinity: *Air* (that is, *oxygen gas*) has a strong affinity for phlogiston: Its presence is necessary during combustion, because it combines with the phlogiston as it separates from the combustible; and it even contributes by its affinity to produce that separation: The moment the air has combined with as much phlogiston as it can receive, or, to use a chemical term, the moment it is *saturated* with phlogiston, combustion necessarily stops, because no more phlogiston can leave the

Supposed, 1. A compound of oxygen and phlogiston,

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* Fourcroy, *Ann. de Chim.* i. 45.

combustible *: Air saturated with phlogiston is azotic gas. This was a very ingenious theory, and, when Dr Priestley published it, exceedingly plausible. A great number of the most eminent chemists accordingly embraced it: But it was soon after discovered, that during combustion the quantity of air, instead of increasing, as it ought to do if phlogiston be added to it, actually diminishes both in bulk and weight. There is no proof, therefore, that during combustion any substance whatever combines with air, but rather the contrary. It was discovered also, that a quantity of air combines with the burning substance during combustion, as we have seen to be the case with sulphur, phosphorus, carbon, and hydrogen; and that this air has the properties of oxygen gas. These discoveries entirely overthrew the evidence on which Dr Priestley's theory was founded: acordingly, as no attempt to decompound azote has succeeded, it has been given up by almost every chemist except Dr Priestley himself.

But erroneously.

More lately, indeed, a new theory concerning the composition of azote has been proposed, and variously modified by different chemists. As this theory has occasioned a controversy which has been maintained in Germany with a good deal of keenness, and which has contributed towards explaining several very curious chemical phenomena, I shall give a short account of the whole in this place.

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* This ingenious theory was first conceived by Dr Rutherford, as appears from the following passage of his thesis. "Ex iisdem etiam deducere licet quod aer ille malignus (azotic gas) componitur ex *aere atmospherico cum phlogisto unito et quasi saturato.* Atque idem confirmatur eo, quod aer qui metallorum calcinationi jam inserviit, et. phlogiston ab iis abripuit, ejusdem plane sit indolis." *De aere Mephitico*, p. 20.

In the year 1783 Dr Priestley discovered, that when earthen ware retorts, moistened with water in the inside, or containing a quantity of moist clay, are heated above the boiling temperature, very little water issues from their beak in the form of vapour; but inſtead of it a quantity of air nearly equal to the weight of the water employed. As this air scarcely differed in its properties from common air, he concluded at first that the water by this process was converted into air. But he afterwards ascertained, by the most ingenious and decisive experiments, that the water which had disappeared had made its way through the pores of the vessel, while at the same time a quantity of external air was forced by the pressure of the atmosphere into the vessel, and that this was the air which issued out of the beak of the retort*.

2. Of Water and fire.

This conclusion was objected to by Achard of Berlin in 1784, who endeavoured to prove, by experiment, that whenever steam is made to pass through red hot earthen tubes, or even metallic tubes, it is converted into azotic gas †. Mr Westrum drew the same conclusion from an experiment of his own; and drew as an inference, that azotic gas is composed of *water* and *heat* combined together ‡. In 1796, Wiegleb published a long paper on the same subject; in which he endeavours, both by reasoning and experiments, to prove the truth of Westrum's theory §. This paper drew the attention of the associated Dutch chemists Deimann, Trootswich, and Lauwerenburg; and induced them to make a very complete set of experiments, an account of

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* Priestley *on air*, ii. 407.

† Crell's *Annals*, 1785, i. 304

‡ *Ibid.* p. 499.

§ *Ibid.* 1796, ii. 467.

which they published 1798*. Their experiments coincided exactly with those of Dr Priestley. No gas made its appearance except when the instruments employed were of earthen ware, and of course capable of being penetrated by air. Wiegleb's method of making the experiment was to lute the tube of a tobacco pipe to a retort containing some pure water. The tobacco pipe was heated red hot by means of a charcoal fire; and then the water in the retort being made to boil, the steam passed through the red hot pipe. The Dutch chemists found, that when instead of the tobacco pipe a glass or metallic tube was used, or when the tobacco pipe was covered with a glass tube, no gas appeared; unless the tube was cracked: and that when gas was obtained, it was always the same with the air on the outside of the tube; that is to say, a mixture of carbonic acid and azotic gas when the tube was heated in a charcoal fire, and common air when the tube was withdrawn from the fire. Thus their experiments coincided precisely with Dr Priestley, and led them to the very same conclusion. Mr Wiegleb attempted to answer the objections of the Dutch chemists, and to establish his own theory by new experiments; but he has by no means succeeded: he has not been able to satisfy even himself †.

3. Of Oxygen and hydrogen,

Soon after Dr Girtanner published a dissertation on the same subject, in the 34th volume of the *Annales de Chimie*. His experiments coincide pretty nearly with those of Wiegleb and his associates; but he drew from them very different consequences, and founded on them

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[*] *Ann. de Chim.* xxvi. 310.

[†] Crell's *Annals*, 1799, i. 45, &c.

a theory almost diametrically opposite. According to him, azotic gas is obtained whenever water in the state of vapour comes into contact with clay. Thus, it is obtained when water is boiled in an earthen retort, or in a glass retort containing a little clay, or ending in an earthen tube. Hence he concludes, that azotic gas is composed of hydrogen and oxygen gas combined together, and differs from water or vapour merely in containing a smaller proportion of oxygen *. These very singular assertions were put to the test of experiment by Berthollet and Bouillon Lagrange. But though they adhered implicitly to the directions of Girtanner, and even varied the process every conceivable way, they did not obtain a particle of azotic gas †. Girtanner therefore either never performed these experiments at all, or he must have been misled by some circumstance or other. His theory of course falls to the ground.

But without proof.

Its component parts unknown.

Thus as all the attempts to decompose azote have hitherto failed, we must of necessity consider it as a simple substance. It must be acknowledged, however, that there are several chemical phenomena altogether inexplicable at present; but which might be accounted for if it were possible to prove that azote is a compound, and that one of the component parts of water enters into its composition. One of these phenomena is the formation of RAIN, which will come under our consideration in the Second Part of this Work: Another is, the constant disengagement of azotic gas when ice is melted. Dr Priestley found, that when water, previously freed from air as completely as possible, is frozen, it emits, when melted again, a quantity of azotic

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[*] *Ann. de Chim.* xxxiv. 3.

[†] *Ibid.* xxxv. 13.

gas. He froze the same water nine times without exposing it to the contact of air, and every time obtained nearly the same proportion of azotic gas *.

SECT. II.

OF MURIATIC ACID.

THIS substance may be procured by the following process :

Preparation.

Let a small pneumatic trough be procured, hollowed out of a single block of wood ; about 14 inches long, 7 broad, and 6 deep. After it has been hollowed out to the depth of an inch, leave 3 inches by way of shelf on one side, and cut out the rest to the proper depth, giving the inside of the bottom a circular form. Fig. 8. represents a section of this trough. Two inches from each end cut a slit in the shelf to the depth of an inch, and broad enough to admit the end of small glass tubes, or the points of small retorts. This trough is to be filled with mercury to the height of $\frac{1}{4}$ inch above the surface of the shelf. Small glass jars are to be procured of considerable thickness and strength, and suitable to the size of the trough. One of them being filled with mercury by plunging it into the trough, is to be placed on the shelf over one of the slits. It ought to be supported in its position ; and the most convenient method of doing that is, to have a brass cylinder two inches high screwed into the edge of the trough just opposite to the border of the shelf. On the top of

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* Nicholson's *Journal*, iv. 193.

it is fixed two flat pieces of brass terminating each in a semicircle, moveable freely upon the brass cylinder, and forming together a brass arm terminating in a circle, the centre of which is just above the middle of the slit in the shelf, when turned so as to be parallel to the edge of the shelf. This circle is made to embrace the jar; being formed of two distinct pieces, its size may be increased or diminished at pleasure, and by means of a brass slider it is made to catch the jar firmly.

The apparatus being thus disposed, two or three ounces of common salt are to be put into a small retort, and an equal quantity of sulphuric acid added; the beak of the retort plunged below the surface of the mercury in the trough, and the heat of a lamp applied to the salt in its bottom. A violent effervefcence takes place; and air bubbles rush in great numbers from its beak, and rise to the surface of the mercury in a visible white smoke, which has a peculiar odour. After allowing a number of them to escape, till it is supposed that the common air which previously existed in the retort has been displaced, plunge its beak into the slit in the shelf over which the glass jar has been placed. The air bubbles soon displace the mercury and fill the jar. The gas thus obtained is called *muriatic acid gas*.

This substance in a state of solution in water was known even to the alchymists; but in a gaseous state it was first examined by Dr Priestley, in an early part of that illustrious career in which he added so much to our knowledge of gaseous bodies.

Properties.

1. Muriatic acid gas is an invisible elastic fluid, resembling common air in its mechanical properties. Its specific gravity, according to the experiments of Mr Kirwan, is 0.002315, or nearly double that of com-

mon air*. Its smell is pungent and peculiar; and whenever it comes in contact with common air, it forms with it a visible white smoke. If a bottle of it be drawn into the mouth, it is found to taste excessively *acid;* much more so than vinegar.

Does not support combustion nor life.

2. Animals are incapable of breathing it, and when plunged into jars filled with it, they die instantaneously in convulsions. Neither will any combustible burn in it. It is remarkable, however, that it has a considerable effect upon the flame of combustible bodies; for if a burning taper be plunged into it, the flame, just before it goes out, may be observed to assume a green colour, and the same tinge appears next time the taper is lighted †.

Absorbed by water.

3. If a little water be let up into a jar filled with this gas, the whole gas disappears in an instant, the mercury ascends, fills the jar, and pushes the water to the very top. The reason of this is, that there exists a strong affinity between muriatic acid gas and water; and whenever they come in contact, they combine and form a liquid; or, which is the same thing, the water absorbs the gas. Hence the necessity of making experiments with this gas over mercury. In the water cistern not a particle of gas would be procured. Nay, the water of the trough would rush into the retort and fill it completely. It is this affinity between muriatic acid gas and water which occasions the white smoke that appears when the gas is mixed with common air. It absorbs the vapour of water which always exists in common air. The solution of muriatic acid gas in water is usually denominated simply *muriatic acid* by chemists.

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* *Irish Trans.*

† Priestley, ii. 293.

We shall have occasion to examine its properties hereafter, when we come to treat of *acids*.

Tinges vegetable blues red.

4. If a little of the blue coloured liquid, which is obtained by boiling red cabbage leaves and water in a tin vessel, be let up into a jar filled with muriatic acid gas, the usual absorption of the gas takes place, but the liquid at the same time assumes a fine red colour. This change is considered by chemists as a characteristic property of *acids*.

Combines with oxygen.

5. Muriatic acid gas is capable of combining with oxygen. To obtain the combination, we have only to put a quantity of the black oxide of manganese in powder into a retort, and pour over it liquid muriatic acid. Heat is then to be applied to the mixture, and the beak of the retort plunged under water. An effervescence takes place, and a green coloured gas comes out at the beak of the retort, which may be received in the usual manner in jars. This gas has been ascertained to be a compound of muriatic acid and oxygen. It is called *oxy-muriatic acid*, and will come under our consideration hereafter.

Action of simple combustibles on it.

6. It does not appear from any experiments that have been hitherto made, that any of the simple combustibles are capable of combining with muriatic acid gas. Dr Priestley found, that sulphur absorbed slowly about the fifth part of it. What remained was *inflammable air* burning with a blue flame, and not absorbed by water *. He found that phosphorus scarcely absorbed any sensible quantity of it, and that charcoal absorbed it very fast †. Hydrogen gas does not produce any sensible change in it. Neither does it seem capable of being affected by azotic gas.

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* Priestley, ii. 283.

† *Ibid.* p.

Simple incombustibles.

Such are the properties of the simple incombustible ubstances. They agree with the simple combustibles n being capable of combining with oxygen.

1. Azote combines with three dozes of oxygen.

Azote, like sulphur, phosphorus and charcoal, comines with three doses of oxygen, and forms three disinct compounds. Combined with the first dose, it orms *nitrous oxide;* with the second, *nitric oxide;* and vhen combined with a maximum of oxygen, it forms *itric acid.* Thus azote and oxygen, combined togeher, form,

1. Nitrous oxide,
2. Nitric oxide,
3. Nitric acid,

r two oxides and one acid. In this respect it resemles charcoal.

2. Muriatic acid with two.

Muriatic acid is capable of combining with two doses f oxygen only. With the first dose, it forms *oxy-muriatic acid;* with the second, *hyperoxy-muriatic acid.* These compounds will be considered afterwards. The irst of them ought, in strict propriety, to be termed n *oxide,* rather than an acid.

Their characteristic property.

What distinguishes the simple incombustibles from he simple combustibles is, their not being capable of burning; for during their combination with oxygen no heat nor light is emitted at whatever temperature the combination takes place. Neither are any of their combinations with oxygen combustible; but they all possess an important and characteristic property. Like oxygen and common air, these combinations are capable of *supporting* combustion.

Azote combines likewise with all the simple combustibles, and forms *sulphureted, phosphureted,* and *carbureted azotic gas,* and *ammonia.* All these compounds (unless the third, which contains only a very small proportion of charcoal, be an exception) are combustible. During combustion, it is the simple combustible of the compound that combines with oxygen, while the azote separates unaltered in the state of gas. Similar combinations of muriatic acid and the simple combustibles are still unknown.

Analogies to be pointed out hereafter lead us to suppose both azote and muriatic acid to be compounds; but till some fortunate experiment ascertain their component parts, we are under the necessity of considering them as simple.

CHAP. IV.

OF METALS.

Properties of metals.

METALS may be considered as the great instruments of all our improvements: Without them, many of the arts and sciences could hardly have existed. So sensible were the ancients of their great importance, that they raised those persons who first discovered the art of working them to the rank of deities. In chemistry, they have always filled a conspicuous station: at one period the whole science was confined to them; and it may be said to have owed its very existence to a rage for making and transmuting metals.

Lustre.

1. One of the most conspicuous properties of the metals is a particular brilliancy which they possess, and which has been called the *metallic lustre*. There are other bodies indeed (*mica* for instance) which apparently possess this peculiar lustre, but in them it is confined to the surface, and accordingly disappears when they are scratched, whereas it pervades every part of the metals. This lustre is occasioned by their reflecting much more light than any other bodies; a property which seems to depend partly on the closeness of their texture. This renders them peculiarly proper for mirrors, of which they always form the basis.

Opacity.

2. They are perfectly opaque, or impervious to light, even after they have been reduced to very thin plates.

Silver leaf, for instance, $\frac{1}{160000}$ of an inch thick, does not permit the smallest ray of light to pass through it. Gold, however, when very thin, is not absolutely opaque: for gold leaf $\frac{1}{280000}$ of an inch thick, when held between the eye and the light, appears of a lively green; and must therefore, as Newton first remarked, transmit the green coloured rays. It is not improbable that all other metals, as the same philosopher supposed, would also transmit light if they could be reduced to a sufficient degree of thinness. It is to this opacity that a part of the excellence of the metals, as mirrors, is owing; their brilliancy alone would not qualify them for that purpose.

Fusibility.

3. They may be melted by the application of heat, and even then still retain their opacity. This property enables us to cast them in moulds, and then to give them any shape we please. In this manner many elegant iron utensils are formed. Different metals differ exceedingly from each other in their fusibility. Mercury is so very fusible, that it is always fluid at the ordinary temperature of the atmosphere; while other metals, as platinum, cannot be melted except by the most violent heat which it is possible to produce.

Weight.

4. Their specific gravity is much greater than that of any other body at present known. Antimony, one of the lightest of them, is more than six times heavier than water; and the specific gravity of platinum, the heaviest of all the metals, is 23. This great density, no doubt, contributes considerably to the reflection of that great quantity of light which constitutes the metallic lustre.

Conducting power.

5. They are the best conductors of electricity of all the bodies hitherto tried.

Hardness.

6. None of the metals are very hard; but some of them may be hardened by art to such a degree as to exceed the hardness of almost all other bodies. Hence the numerous cutting instruments which the moderns make of steel, and which the ancients made of a combination of copper and tin.

Elasticity.

7. The elasticity of the metals depends upon their hardness; and it may be increased by the same process by which their hardness is increased. Thus the steel of which the balance-springs of watches is made is almost perfectly elastic, though iron in its natural state possesses but little elasticity.

Malleability.

8. But one of their most important properties is *malleability*, by which is meant the capacity of being extended and flattened when struck with a hammer. This property, which is peculiar to metals, enables us to give the metallic body any form we think proper, and thus renders it easy for us to convert them into the various instruments for which we have occasion. All metals do not possess this property; but it is remarkable that almost all those which were known to the ancients have it. Heat increases this property considerably. Metals become harder and denser by being hammered.

Ductility.

9. Another property, which is also wanting in many of the metals, is *ductility*; by which we mean the capacity of being drawn out into wire by being forced thro' holes of various diameters.

Tenacity.

10. Ductility depends, in some measure, on another property which metals possess, namely *tenacity*; by which is meant the power which a metallic wire of a given diameter has of resisting, without breaking, the action of a weight suspended from its extremity. Metals differ exceedingly from each other in their tenacity.

An iron wire, for instance, $\frac{1}{10}$th of an inch in diameter, will support, without breaking, about 500 lb. weight; whereas a lead wire, of the same diameter, will not support above 29 lb.

Calcination.

11. When exposed to the action of heat and air, most of the metals lose their lustre, and are converted into earthy-like powders of different colours and properties, according to the metal and the degree of heat employed. Several of the metals even take fire when exposed to a strong heat; and after combustion the residuum is found to be the very same earthy-like substance.

Reduction.

12. If any of these *calces*, as they are called, be mixed with charcoal-powder, and exposed to a strong heat in a proper vessel, it is changed again to the metal from which it was produced. From these phenomena Stahl concluded, that metals are composed of *earth* and *phlogiston*. He was of opinion, that there is only one primitive earth, which not only forms the basis of all those substances known by the name of earths, but the basis also of all the metals. He found, however, that it was impossible to combine any mere earth with phlogiston; and concluded, therefore, with Beccher, that there is another principle besides earth and phlogiston which enters into the composition of the metals. To this principle Beccher gave the name of *mercurial earth*, because, according to him, it exists most abundantly in *mercury*. This principle was supposed to be very volatile, and therefore to fly off during calcination: and some chemists even affirmed that it might be obtained in the soot of those chimneys under which metals have been calcined.

Stahl's theory of their component parts.

A striking defect was soon perceived in this theory. The original metal may be again produced by heating its calx along with some other substance which contains phlogiston. Now, if the mercurial earth flies off during combustion, it cannot be necessary for the formation of complete metals, for they may be produced without it: if, on the contrary, it adheres always to the calx, there is no proof of its existence at all. Chemists, in consequence of these observations, found themselves obliged to discard the mercurial principle altogether, and to conclude, that metals are composed of earth only, united to phlogiston. But if this be really the case, how comes it that these two substances cannot be united by art? Henkel was the first who attempted to solve this difficulty. According to him, earth and phlogiston are substances of so opposite a nature, that it is exceedingly difficult, or rather it has been hitherto impossible, for us to commence their union; but after it has been once begun by Nature, it is an easy matter to complete it. No calcination has hitherto deprived the metals of all their phlogiston; some still adheres to the calces. It is this remainder of phlogiston which renders it so easy to restore them to their metallic state. Were the calcination to be continued long enough to deprive them altogether of phlogiston, they would be reduced to the state of other earths; and then it would be equally difficult to convert them into metals, or, to use a chemical term, to *reduce* them. Accordingly we find, that the more completely a calx has been calcined, the more difficult is its reduction. This explanation was favourably received. But after the characteristic properties of the various *earths* had been ascertained, and the calces of metals were accurately examined, it was perceived that the calces differ in many particulars from all the *earths*, and from one another. To call them all the

Improved by Henkel,

And Bergman.

ſame substance, then, was to go much farther than either experiment or observation would warrant, or rather, it was to declare open war against both experiment and observation. It was concluded, therefore, that each of the metals is composed of a peculiar *earthy substance* combined with phlogiston. For this great improvement in accuracy, chemistry is chiefly indebted to Bergman.

Refuted by Lavoisier.

But there were several phenomena of calcination which had all this time been unaccountably overlooked. The calces are all considerably heavier than the metals from which they are obtained. Boyle had observed this circumstance, and had ascribed it to a quantity of *fire* which, according to him, became fixed in the metal during the process*. But succeeding chemists paid little atention to it, or to the action of air, till Mr Lavoisier published his celebrated experiments on calcination, in the Memoirs of the Paris Academy for 1774. He put eight ounces of *tin* into a large glass retort, the point of which was drawn out into a very slender tube to admit of easy fusion. The retort was heated slowly till the tin began to melt, and then sealed hermetically. This heat was applied to expel some of the air from the retort; without which precaution it would have expanded and burst the vessel. The retort, which was capable of containing 250 cubic inches, was then weighed accurately, and placed again upon the fire. The tin soon melted, and a pellicle formed on its top, which was gradually converted into a grey powder, that sunk by little agitation to the bottom of the liquid metal:

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* Fire and flame weighed, *Shaw's Boyle*, ii. 388.

in short, the tin was partly converted into a *calx*. This process went on ſor three hours; after which the calcination ſtopped, and no further change could be produced on the metal. The retort was then taken from the fire, and found to be precisely of the same weight as before the operation. It is evident, then, that no new substance had been introduced; and that therefore the increased weight of calces cannot, as Boyle supposed, be owing to the fixation of fire*.

When the point of the retort was broken, the air rushed in with a hissing noise, and the weight of the retort was increased by ten grains. Ten grains of air, therefore, must have entered, and, consequently, precisely that quantity must have disappeared during the calcination. The metal and its calx being weighed, were found just ten grains heavier than before: therefore the air which disappeared was absorbed by the metal: and as that part of the tin which remained in a metallic state was unchanged, it was evident that this air must have united with the calx. The increase of weight, then, which metals experience during calcination, is owing to their uniting with air†. But all the

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* This experiment had been performed by Boyle with the same success. He had drawn a wrong conclusion from not attending to the state of the air of the vessel. *Shaw's Boyle*, ii. 394.

† It is remarkable that John Rey, a physician of Perigord, had ascribed it to this very cause as far back as the year 1630: But his writings had excited little attention, and had sunk into oblivion, till his opinion had been incontestibly proved by Lavoisier. Mayow also, in the year 1674, ascribed the increase of weight to the combination of metals with oxygen. " Quippe vix concipi potest (says he), unde augmentum illud antimonii (calcinati) nisi a particulis nitro aereis igneisque inter calcinandum FIXIS procedat." *Tract.* p. 28.—" Plane ut antimonii ſixatio non

Book I.
Division I.

air in the vessel was not absorbed, and yet the calcination would not go on. It is not the whole, then, but some particular part of the air which unites with the calces of metals. By the subsequent discoveries of Priestley, Scheele, and Lavoisier himself, it has been ascertained, that the residuum of the air, after calcination has been performed in it, is always pure azotic gas: It follows, therefore, that it is only the *oxygen* which combines with calces; and that a metallic calx is not a simple substance, but a compound.

Mr Lavoisier observed, that the weight of the calx was always equal to that of the metal employed, together with that of the oxygen absorbed. It became a question, then, Whether metals, during calcination, lose any substance, and, consequently, whether they contain any phlogiston? Mr Lavoisier accordingly proposed this question; and he answered it himself by a number of accurate experiments and ingenious observations. Metals cannot be calcined, excepting in contact with oxygen, and in proportion as they combine with it. Consequently they not only absorb oxygen during their calcination, but that absorption is absolutely necessary to their assuming the form of a calx. If the calx of mercury be heated in a retort, to which a pneumatic apparatus is attached, to the temperature of 1000°, it is converted into pure mercury; and, at the same time, a quantity of oxygen separates from it in a gaseous form. As this process was performed in a close vessel, no new substance could enter: The calx of mercury, then, was reduced to a metallic state without phlogiston.

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tam a sulphuris ejus externi assumptione, quam particulis nitro-aereis, quibus flamma nitri abundat, EI INFIXIS provenire videatur." *Ibid* p. 29.

The weights of the metal, and the oxygen gas, are together just equal to that of the calx ; the calx of mercury, therefore, must be composed of mercury and oxygen ; consequently, there is no reason whatever to suppose that mercury contains phlogiston. Its calcination is merely the act of its uniting with oxygen *. The calces of lead, silver, and gold, may be decomposed exactly in the same manner ; and Mr Van Marum, by means of his great electrical machine, decomposed also those of tin, zinc, and antimony, and resolved them into their respective metals and oxygen †. The same conclusions, therefore, must be drawn with respect to these metals. All the metallic calces may be decomposed by presenting to them substances which have a greater affinity for oxygen than they have. This is the reason that charcoal-powder is so efficacious in reducing them : and if they are mixed with it, and heated in a proper vessel furnished with a pneumatic apparatus, it will be easy to

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* This experiment was performed by Mr Bayen in 1774. This philosopher perceived, earlier than Lavoisier, that all metals did not contain phlogiston. " Ces experiences (says he) vont nous detromper. Je ne tiendrai plus le langage des disciples de Stahl, qui seront forcés de restreindre la doctrine sur le phlogistique, ou d'avouer que les precipités mercurials, dont je parle, ne sont pas des chaux metalliques, ou enfin qu'il y a des chaux qui peuvent se reduire sans le concours du phlogistique. Les experiences que j'ai faites me force de conclure que dans la chaux mercuriale dont je parle, le mercure doit son *etat calcaire, non à la perte du phlogistique* qu'il n'a pas essuyée, *mais à sa combinaison intime avec le fluide elastique*, dont le poids ajouté a celui du mercure est la seconde cause de l'augmentation de pesanteur q'on observe dans les precipités que j'ai soumis à l'examen." *Jour. de Phys.* 1774, pages 288, 295.—It was in consequence of hearing Bayen's paper read that Lavoisier was induced to turn his attention to the subject.

† *Jour. de Phys.* 1785.

discover what passes. During the reduction, a great deal of carbonic acid gas comes over, which, together with the metal, is equal to the weight of the calx and the charcoal: it must therefore contain all the ingredients; and we know that carbonic acid gas is composed of carbon and oxygen. During the process, then, the oxygen of the calx combines with the charcoal and the metal remains behind. It cannot be doubted, therefore, that all the metallic calces are composed of the entire metals combined with oxygen; and that calcination, like combustion, is merely the act of this combination. All metals, then, in the present state of chemistry, must be considered as simple substances; for they have never yet been decompounded.

Oxide and oxidizement explained.

The words *calx* and *calcination* are evidently improper, as they convey false ideas; we shall therefore afterwards employ, instead of them, the words *oxide* and *oxidizement**, which were invented by the French chemists. A metallic *oxide* signifies a metal united with oxygen; and *oxidizement* implies the act of that union.

Metals combine with oxygen.

13. Metals, then, are all capable of combining with oxygen; and this combination is sometimes accompanied by combustion and sometimes not. The new compounds formed are called *metallic oxides*, and in some cases *metallic acids*. Like the two last classes of bodies, they are capable of combining with different doses of oxygen, and of forming different species of oxides or acids. These were formerly distinguished from each

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* *Oxidation* was the word formerly used by British chemists. But the reasons assigned by Mr Chenevix in his *Remarks on the Chemical Nomenclature*, page 163, have induced me to prefer the terms which he has there substituted for it.

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other by their colour. One of the oxides, for instance, was called *black oxide*, another was termed *red oxide*; but it is now known that the same oxide is capable of assuming different colours according to circumstances. The mode of naming them from their colour, therefore, wants precision, and is apt to mislead; especially as there occur different examples of two distinct oxides of the same metal having the same colour.

Nomenclature of oxides.

As it is absolutely necessary to be able to distinguish the different oxides of the same metal from each other with perfect precision, and as the present chemical nomenclature is defective in this respect, I shall, till some better method be proposed, distinguish them from each other, by prefixing to the word *oxide* the first syllable of the Greek ordinal numerals. Thus the *protoxide* of a metal will denote the metal combined with a minimum of oxygen, or the *first oxide* which the metal is capable of forming; *deutoxide* will denote the second oxide of a metal, or the metal combined with two doses of oxygen [*]. When a metal has combined with as much oxygen as possible, I shall denote the compound formed by the term *peroxide*; indicating by it, that the metal is thoroughly oxidized [†].

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[*] The same explanation will apply to *tritoxide* (third oxide), *tetoxide* (fourth oxide), *pentoxide* (fifth oxide), *hectoxide* (sixth oxide), whenever they become necessary.

[†] Etymologists will doubtless object to this term, that it is a heterogeneous compound of a Greek and Latin word; but this fault, if it be one, has been already committed, very frequently, in the formation of chemical terms. My object was, not to prevent the objections of etymologists, but to employ a word perfectly precise, which could not mislead, and which was not unwieldy, nor unsuitable to the genius of the English language.

Thus we have the term *oxide* to denote the combination of metals with oxygen in general; the terms *protoxide* and *peroxide* to denote the minimum and maximum of oxidizement; and the terms *deutoxide*, *tritoxide*, &c. to denote all the intermediate states which are capable of being formed.

Combine with simple combustibles,

14. Metals are capable also of combining with the simple combustiblse. The compounds thus formed are denoted by the simple combustible which enters into the combination, with the termination *uret* added to it. Thus the combination of a metal with sulphur, phosphorus, or carbon, is called the *sulphuret*, *phosphuret*, or *carburet* of the metal. Hydrogen has not been proved capable of entering into similar combinations; neither have the simple incombustibles.

And with each other.

15. The metals are capable likewise of combining with each other, and of forming compounds, some of which are extremely useful in the manufacture of instruments and utensils. Thus *pewter* is a compound of lead and tin; *brass*, a compound of copper and zinc; *bell-metal*, a compound of copper and tin. These metallic compounds are called by chemists *alloys*, except when one of the combining metals is *mercury*. In that case the compound is called an *amalgam*. Thus the compound of mercury and gold is called the *amalgam of gold*.

Metals divisible into three classes.

16. The metals at present amount to 23; only 11 of which were known before the year 1730. They may be very conveniently arranged under three classes; namely, 1. Malleable Metals; 2. Brittle and easily fusible Metals; 3. Brittle and difficultly fusible Metals. The metals belonging to each of these classes will be seen from the following Table:

I. Malleable.

1. Gold.
2. Platinum.
3. Silver.
4. Mercury.
5. Copper.
6. Iron.
7. Tin.
8. Lead.
9. Nickel.
10. Zinc.

II. Brittle and easily Fused.

1. Bismuth.
2. Antimony.
3. Tellurium.
4. Arsenic.

III. Brittle and difficultly Fused.

1. Cobalt.
2. Manganese.
3. Tungsten.
4. Molybdenum.
5. Uranium.
6. Titanium.
7. Chromium.
8. Columbium.
9. Tantalium.

The metals of the first class were formerly called *metals* by way of eminence, because they are possessed either of malleability or ductility, or of both properties together: the rest were called *semimetals*, because they are brittle. But this distinction is now pretty generally laid aside; and, as Bergman observes, it ought to be so altogether, as it is founded on a false hypothesis, and conveys very erroneous ideas to the mind. The first four metals were formerly called *noble* or *perfect metals*, because their oxides are reducible by the mere application of heat; the next four were *imperfect metals*, because their oxides were thought not reducible without the addition of some combustible substance; but this distinction also is now very properly exploded.

SECT. I.

OF GOLD.

I. GOLD seems to have been known from the very beginning of the world. Its properties and its scarcity have rendered it more valuable than any other metal.

Properties of gold.

1. It is of an orange red, or reddish yellow colour, and has no perceptible taste or smell. Its lustre is considerable, yielding only to that of platinum, steel, silver, and mercury.

2. Its hardness is $6\frac{1}{2}$*; its specific gravity 19.3.

Malleability.

3. No other substance is equal to it in ductility and malleability. It may be beaten out into leaves so thin, that one grain of gold will cover $56\frac{3}{4}$ square inches. These leaves are only $\frac{1}{282000}$ of an inch thick. But

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* Mr Kirwan's method of denoting the different degrees of hardness by figures is used throughout this Treatise. These figures will be understood by Mr Kirwan's own explanation, which is here subjoined.

3, Denotes the hardness of chalk.

4, A superior hardness, but yet what yields to the nail.

5, What will not yield to the nail, but easily, and without grittiness, to the knife.

6, That which yields more difficultly to the knife.

7, That which scarcely yields to the knife.

8, That which cannot be scraped by a knife, but does not give fire with steel.

9, That which gives a few feeble sparks with steel.

10, That which gives plentiful lively sparks.—*Kirwan's Mineralogy*, i. 38

the gold leaf with which silver wire is covered has only $\frac{1}{11}$ of that thickness. An ounce of gold, upon silver wire, is capable of being extended more than 1300 miles in length[*].

Tenacity.

4. Its tenacity is considerable, though in this respect it yields to iron, copper, platinum, and silver. From the experiments of Sickingen it appears that a gold wire 0.078 inch in diameter is capable of supporting a weight of 150.07 lbs. avoirdupois, without breaking[†].

Action of heat.

5. It melts at 32° of Wedgewood's pyrometer[‡]. When melted, it assumes a bright bluish green colour. It expands in the act of fusion, and consequently contracts while becoming solid more than most metals; a circumstance which renders it less proper for casting into moulds.

It requires a very violent heat to volatilize it; it is therefore, to use a chemical term, exceedingly *fixed.* Boyle and Kunkel kept it for some months in a glass-house furnace, and yet it underwent no change; nor did it lose any perceptible weight, after being exposed for some hours to the utmost heat of Mr Parker's lens[§]. Homberg, however, observed, that when a very small portion of gold is kept in fusion, part of it is volatilized. This observation was confirmed by Macquer, who observed the metal rising in fumes to the height of five or six inches, and attaching itself to a plate of silver, which it gilded very accurately; and Mr Lavoisier observed the very same thing when a piece of silver was

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[*] See Shaw's *Boyle*, i. 404.

[†] *Ann. de Chim.* xxv. 9.

[‡] According to the calculation of the Dijon academicians, it melts at 1298° Fahrenheit; according to Mortimer, at 1301°.

[§] Kirwan's *Mineralogy*, i. 92.

held over gold melted by a fire blown by oxygen gas, which produces a much greater heat than common air.

After fusion, it is capable of assuming a crystalline form. Tillet and Mongez obtained it in short quadrangular pyramidal crystals.

6. Gold is not in the least altered by being kept exposed to the air; it does not even lose its lustre. Neither has water the smallest action upon it.

Oxides two.

II. It is capable, however, of combining with oxygen, and even of undergoing combustion in particular circumstances. The resulting compound is an *oxide of gold*. There are two oxides of gold; the protoxide is of a purple or violet, the peroxide of a yellow colour.

1. Protoxide.

1. Gold must be raised to a very high temperature before it is capable of abstracting oxygen from common air. It may be kept red hot almost any length of time without any such change. Homberg, however, observed, that when placed in the focus of Tschirnhausen's burning glass, its surface became covered with a purple coloured oxide; and the truth of his observations were put beyond doubt by the subsequent experiments of Macquer with a still more powerful burning glass. It was remarked also in 1773 by Camus, that when the electric explosion is transmitted through gold leaf placed between two plates of glass, or when a strong charge is made to fall on a gilded surface—in both cases the metal is oxidized, and assumes a purple colour. The reality of the oxidizement of gold by electricity was disputed by some philosophers, but it has been put beyond the reach of doubt by the experiments of Van Marum. When that celebrated philosopher made electric sparks from the powerful Teylerian machine pass through a gold wire suspended in the air, it took fire,

burnt with a green coloured flame, and was completely dissipated in fumes, which when collected proved to be a purple coloured oxide of gold. This combustion, according to Van Marum, succeeded not only in common air, but also when the wire was suspended in hydrogen gas and other gases which are not capable of supporting combustion. These singular observations would require to be verified by other experiments before any conclusion can be drawn from them. The combustion of gold is now easily affected by exposing gold-leaf to the action of the galvanic pile *. I have made it burn with great brilliancy by exposing a gold wire to the action of a stream of oxygen and hydrogen gas mixed together and burning. In all cases of the combustion of gold, it has been ascertained that the *protoxide*, or *purple coloured oxide*, only is formed.

2. Peroxide.

2. The *peroxide*, or yellow coloured oxide, may be procured in the following manner: Equal parts of nitric and muriatic acids are mixed together †, and poured upon gold; an effervescence takes place, the gold is gradually dissolved, and the liquid assumes a yellow colour. It is easy to see in what manner this solution is produced. No metal is soluble in acids till it has been reduced to the state of an oxide. There is a strong affinity between the oxide of gold and muriatic acid. The nitric acid furnishes oxygen to the gold, and the muriatic acid dissolves the oxide as it forms. When nitric acid is deprived of the greater part of its oxygen,

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* The method of making this experiment will be described hereafter.

† This mixture, from its property of dissolving gold, was formerly called *aqua regia* (for gold, among the alchymists, was the king of metals); it is now called *nitro-muriatic acid.*

it assumes a gaseous form, and is then called *nitrous gas*, or more properly *nitric oxide gas*. It is the emission of this gas which causes the effervescence. The oxide of gold may be precipitated from the nitro-muriatic acid, by pouring in a little potass dissolved in water, or, which is much better, a little lime; both of which have a stronger affinity for muriatic acid than the oxide has.

How decomposed.

The oxides of gold may be decomposed in close vessels by the application of heat. The gold remains fixed, and the oxygen assumes the gaseous form. They may be decomposed, too, by all the substances which have a stronger affinity for oxygen than gold has.

Action of combustibles.

III. Hitherto gold has not been found capable of combining with sulphur, carbon, or hydrogen. Mr Pelletier combined it with phosphorus, by melting together in a crucible half an ounce of gold and an ounce of phosphoric glass *, surrounded with charcoal. The *phosphuret of gold* thus produced was brittle, whiter than gold, and had a crystallized appearance. It was composed of 23 parts of gold and one of phosphorus †. He formed the same compound by dropping small pieces of phosphorus into gold in fusion ‡. Phosphorus, then, is the only one of the simple combustibles with which gold at present is supposed capable of combining.

Phosphuret of old.

Of incombustibles.

IV. Neither does gold combine, as far as is known, with either of the simple incombustible bodies.

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* Phosphoric acid evaporated to dryness, and then fused.

† *Ann. de Chim.* i. 71.

‡ *Ibid.* xiii. 104.

Alloys.

V. But gold combines readily with the greater number of the metals, and forms a variety of alloys.

Affinities.

VI. The affinities of gold and its oxides are placed by Bergman in the following order:

GOLD.	OXIDE OF GOLD.
Mercury,	Muriatic acid,
Copper,	Nitric,
Silver,	Sulphuric,
Lead,	Arsenic,
Bismuth,	Fluoric,
Tin,	Tartaric,
Antimony,	Phosphoric,
Iron,	Prussic.
Platinum,	
Zinc,	
Nickel,	
Arsenic,	
Cobalt,	
Manganese.	

SECT. II.

OF PLATINUM.

GOLD, the metal just described, was known in the earliest ages, and has been always in high estimation, on account of its scarcity, beauty, ductility, and indestructibility. But platinum, though perhaps inferior in few of these qualities, and certainly far superior in others, was unknown, as a distinct metal, before the year 1752*.

History of platinum.

I. It has hitherto been found only in America in Choco in Peru, and in the mine of Santa Fe, near Carthage-

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* Father Cortinovis, indeed, has attempted to prove, that this metal was the *electrum* of the ancients. See the *Chemical Annals of Brugnatelli*, 1790. That the *electrum* of the ancients was a metal, and a very valuable one, is evident from many of the ancient writers, particularly Homer. The following lines of Claudian are alone sufficient to prove it:

"Atria cinxit ebur, trabibus solidatur ahenis
"Culmen et in celsas surgunt *electra* columnas." L. I. v. 164.

Pliny gives us an account of it in his Natural History. He informs us that it was a composition of silver and gold; and that by candle-light it shone with more splendor than silver. The ancients made cups, statues, and columns of it. Now. had it been our platinum, is it not rather extraordinary that no traces of a metal, which must have been pretty abundant, should be perceptible in any part of the old continent?

As the passage of Pliny contains the fullest account of electrum to be found in any ancient author, I shall give it in his own words, that every one may have it in his power to judge whether or not the description will apply to the platinum of the moderns.

"Omni auro inest argentum vario pondere.—Ubicunque quinta argenti portio est, *electrum* vocatur. Scrobes eæ reperiuntur in Canaliensi. Fit na [*]. The workmen of these mines must no doubt have been early acquainted with it; but they seem to have paid very little attention to it. It was unknown in Europe till Mr Wood brought some of it from Jamaica in 1741. In 1748 it was noticed by Don Antonio de Ulloa, a Spanish mathematician, who had accompanied the French academicians to Peru in their voyage to measure a degree of the meridian. Several papers on it were published by Dr Watson in the 46th volume of the Philosophical Transactions. These immediately attracted the attention of the most eminent chemists. In 1752, Mr Scheffer of Sweden published the first accurate examination of its properties. He proved it to be a new metal, approaching very much to the nature of gold, and therefore gave it the name of *aurum album*, "white gold." Dr Lewis published a still more complete set of experiments on it in 1754 [†]. Soon after dissertations were published on it by Margraf [‡]; Macquer, and Baumé [§]; Buffon, Tillet, and Morveau [||]; Sickingen [¶], Bergman[**], and more lately by Mussin

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et cura electrum argento addito. Quod si quintam portionem excessit, ncudibus non restitit. Et electro auctoritas, Homero teste, qui Menelai regiam auro, electro, argento, ebore fulgere tradit. Minervæ templum habet Lindos insulæ Rhodiorum in quo Helena sacravit calicem ex elecro.—Electri natura est ad lucernarum lumina clarius argento splendere. Quod est nativum, et venena deprehendit. Namque discurrunt in calicibus arcus cœlestibus similes cum igneo stridore, et gemina ratione prædiunt."—Lib. xxxiii. cap. iv.

[*] A platinum mine is said to have been lately discovered in South America.

[†] *Phil. Trans.* xlviii. 638. and l. 148.

[‡] *Mem. Berlin* 1757, p. 314.

[§] *Mem. Par.* 1758, p. 119.

[||] *Journ. de Phys.* iii. 324.

[¶] Macquer's *Dictionary*.

[**] *Opusc.* ii. 166.

Book I. Division I.

The Properties.

Puschkin *, and Morveau †, and several other chemists of eminence.

1. Platinum, when pure, is of a white colour like silver, but not so bright ‡. It has no taste nor smell.

2. Its hardness is 8. Its specific gravity, after being hammered, is 23.000; so that it is by far the heaviest body known §.

3. It is exceedingly ductile and malleable; it may be hammered out into very thin plates, and drawn into wires not exceeding $\frac{1}{1940}$ inch in diameter. In these properties it is probably inferior to gold, but it seems to surpass all the other metals.

4. Its tenacity is such, that a wire of platinum 0.078 inch in diameter is capable of supporting a weight of 274.31 lbs avoirdupois without breaking ‖.

5. It is the most infusible of all metals, and cannot be melted, in any quantity at least, by the strongest artificial heat which can be produced. Macquer and Baumé melted small particles of it by means of a blow-pipe, and Lavoisier by exposing them on red hot charcoal to a stream of oxygen gas. It may indeed be melted without difficulty when combined or mixed with other bodies, but then it is not in a state of purity. Pieces of platinum, when heated to whiteness, may be welded together by hammering in the same manner as hot iron.

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* *Ann. de Chim.* xxiv. 205.

† *Ann. de Chim.* xxv. 3.

‡ To this colour it owes it name. *Plata*, in Spanish, is "silver;" and *platina*, "little silver," was the name first given to the metal. Bergman changed that name into *platinum*, that the Latin names of all the metals might have the same termination and gender. It had been, however, called *platinum* by Linnæus long before.

§ Kirwan's *Miner.* ii. 103.

‖ Morveau, *Ann. de Chim.* xxv. 7.

6. This metal is not in the smallest degree altered by the action of air or water.

Oxide.

II. It cannot be combined with oxygen and converted into an oxide by the strongest artificial heat of our furnaces. Platinum, indeed, in the state in which it is brought from America, may be partially oxidated by exposure to a violent heat, as numerous experiments have proved; but in that state it is not pure, but combined with a quantity of iron. It cannot be doubted, however, that if we could subject it to a sufficient heat, platinum would burn and be oxidated like other metals: For when Van Marum exposed a wire of platinum to he action of his powerful electrical machine, it burnt with a faint white flame, and was dissipated into a spe-ies of dust, which proved to be the oxide of platinum, By putting a platinum wire into the flame produced by he combustion of hydrogen gas mixed with oxygen, I aused it to burn with all the brilliancy of iron wire, nd to emit sparks in abundance. This metal may be xidated in any quantity by boiling it in sixteen times s weight of nitro-muriatic acid. The acid dissolves it, nd assumes first a yellow, and afterwards a deep red r rather brown colour. On the addition of lime to ne solution, a yellow powder falls to the bottom. his powder is the *oxide* of platinum. Its properties ave not been examined with sufficient accuracy. It eems to contain but a small proportion of oxygen; pro-ably not more than 0.07 *. Yet it is in all probabi-ty a peroxide.

This oxide may be decomposed, and the oxygen dri-en off by exposing it to a violent heat †.

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* Fourcroy, vi. 428.

† Macquer's *Dictionary*.

Combination with combustibles.

III. Neither carbon nor hydrogen can be combined with platinum ; but Mr Proust has found it combined with sulphur in native platina *, and it unites without difficulty to phosphorus. By mixing together an ounce of platinum, an ounce of phosphoric glass, and a dram of powdered charcoal, and applying a heat of about 32° Wedgewood, Mr Pelletier formed a *phosphuret of platinum* weighing more than an ounce. It was partly in the form of a button, and partly in cubic crystals. It was covered above by a blackish glass. It was of a silver white colour, very brittle, and hard enough to strike fire with steel. When exposed to a fire strong enough to melt it, the phosphorus was disengaged, and burnt on the surface †.

Phosphuret.

He found also, that when phosphorus was projected on red hot platinum, the metal instantly fused and formed a phosphuret. As heat expels the phosphorus, Mr Pelletier has proposed this as an easy method of purifying platinum ‡.

IV. Platinum, as far as is known, does not combine with the simple incombustibles.

Alloys

V. It combines with most of the metals and forms alloys.

with gold.

When gold and platinum are exposed to a strong heat, they combine, and form an *alloy* of gold and platinum. If the platinum exceed $\frac{1}{17}$ of the gold, the colour of the alloy is much paler than gold ; but if it be under $\frac{1}{17}$, the colour of the gold is not sensibly altered. Neither is there any alteration in the ductility of the gold. Platinum may be alloyed with a considerable pro-

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* *Ann. de Chim.* 38. 149.

† *Ibid.* i. 71.

‡ *Ibid.* xiii. 105.

ortion of gold without sensibly altering its colour. hus an alloy of one part of platinum with four parts of old can scarcely be distinguished in appearance from ure platinum. The colour of gold does not become redominant till it constitutes eight-ninths of the al- y *.

VI. Neither the affinities of platinum nor of its oxide e at present known.

If this metal could be obtained at a cheap rate, it ould furnish very precious vessels; as they would not e acted upon by almost any body, would not be liable be broken, and might be exposed to the greatest heat ithout alteration. It might be employed, too, with ery great advantage instead of silver, to cover the sur- ace of copper and iron utensils.

SECT. III.

OF SILVER.

. **SILVER** seems to have been known almost as early s gold.

1. It is a metal of a fine white colour, without either Properties. aste or smell; and in point of brilliancy is perhaps in- erior to none of the metallic bodies, if we except po- ished steel.

2. Its hardness is 7. When melted, its specific gra- ity is 10.478; when hammered, 10.609.

3. In malleability, it is inferior to none of the me-

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* Klaproth, *Journal de Chimie*, iv. 29.

tals, if we except gold, and perhaps also platinum. It may be beat out into leaves only $\frac{1}{160000}$ inch thick. Its ductility is equally remarkable : it may be drawn out into wire much finer than a human hair ; so fine indeed, that a single grain of silver may be extended about 400 feet in length.

4. Its tenacity is such, that a wire of silver 0.078 inch in diameter is capable of supporting a weight of 187.13 lbs avoirdupois without breaking *.

5. Silver melts when it is heated completely red hot ; and while melted its brilliancy is much increased. According to the calculation of Bergman and Mortimer, its fusing point is 1000° of Fahrenheit. It continues melted at 28° Wedgewood, but requires a greater heat to bring it to fusion †. If the heat be increased after the silver is melted, the liquid metal boils, and may be volatilized ; but a very strong and long continued heat is necessary.

When cooled slowly, its surface exhibits the appearance of crystals ; and if the liquid part of the metal be poured out as soon as the surface congeals, pretty large crystals of silver may be obtained. By this method Tillet, and Mongez junior, obtained it in four-sided pyramids, both insulated and in groups.

Oxides.

II. Silver is not oxidated by exposure to the air : it gradually indeed loses its lustre, and becomes tarnished ; but this is owing to a different cause. Neither is it altered by being kept under water. But if it be kept for a long time melted in an open vessel, it gradually attracts the oxygen from the atmosphere, and is converted into an oxide. This experiment was first made by

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* *Ann. de Chim.* xxv. 9.

† Kirwan's *Miner.* ii. 107.

Junker, who converted a quantity of silver into a vitri-orm oxide. It was afterwards confirmed by Macquer nd Darcet. Macquer, by exposing silver 20 times uccessively to the heat of a porcelain furnace, obtained *glass*[*] of an olive green colour [†]. Nay, if the heat be ufficient, the silver even takes fire and burns like other ombustible bodies. Van Marum made electric sparks rom his powerful Teylerian machine pass through a ilver wire; the wire exhibited a greenish white flame, nd was dissipated into smoke. Before a stream of oxy-en and hydrogen gas, it burns rapidly with a light green ame.

The oxide of silver, obtained by means of heat, is of greenish or yellowish grey colour; and is easily de-omposed by the application of heat in close vessels, or ven by exposing it to the light. When silver is dis-olved in nitric acid, and precipitated by lime water, it alls to the bottom under the form of a powder, of a ark greenish brown colour. From the experiments of Venzel and Bergman it follows, that the greenish or ellowish grey oxide is composed of about 90 parts of ilver and 10 of oxygen [‡]. When this oxide is exposed the light, part of its oxygen is separated, as Scheele irst ascertained, and it is converted into a black pow-er which contains but a very small portion of oxygen, nd may be considered as silver reduced. By exposing he solution of silver in nitric acid to sunshine, the sil-er precipitates in the form of a flea-brown powder.

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[*] Metallic oxides, after fusion, are called *glass*, because they acquire a ood deal of resemblance, in some particulars, to common glass.

[†] Macquer's *Dictionary*.

[‡] Kirwan's *Miner.* ii. 493.

Combination with combustibles.

III. Neither carbon nor hydrogen have been combined with silver; but it combines readily with sulphur and phosphorus.

Sulphuret.

1. When thin plates of silver and sulphur are laid alternately above each other in a crucible, they melt readily in a low red heat, and form *sulphuret of silver*. It is of a black or very deep violet colour; brittle, but capable of being cut with a knife; often crystallized in small needles; and much more fusible than silver. If sufficient heat be applied, the sulphur is slowly volatilized, and the metal remains behind in a state of purity. It is very difficult to determine the proportion of the ingredients which enter into the compoſition of this substance, because there is an affinity between silver and its sulphuret, which disposes them to combine together. The greatest quantity of sulphur which a given quantity of silver is capable of taking up, is, according to Wenzel, $\frac{13}{100}$*.

It is well known, that when silver is long exposed to the air, especially in frequented places, as churches, theatres, &c. it acquires a covering of a violet colour, which deprives it of its lustre and malleability. This covering, which forms a thin layer, can only be detached from the silver by bending it, or breaking it in pieces with a hammer. It was examined by Mr Proust, and found to be *sulphuret of silver* †.

Phosphuret.

2. Silver was first combined with phosphorus by Mr Pelletier. If one ounce of ſilver, one ounce of phosphoric glass, and two drams of charcoal, be mixed together, and heated in a crucible, *phosphuret of sulphur* is form-

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* Kirwan's *Miner.* ii. 492.

† *Ann. de Chim.* i. 142.

d. It is of a white colour, and appears granulated, or s it were crystallized. It breaks under the hammer, ut may be cut with a knife. It is composed of four arts of silver and one of phosphorus. Heat decomoses it by separating the phosphorus *. Pelletier has bserved, that silver in fusion is capable of combining vith more phosphorus than solid silver: for when hosphuret of silver is formed by projecting phosphous into melted silver, after the crucible is taken from he fire, a quantity of phosphorus is emitted the monent the metal congeals †.

IV. Silver does not combine with the simple incomustibles,

Alloys

V. Silver combines readily with the greater number f metallic bodies.

with gold.

1. When silver and gold are kept melted together, hey combine, and form an alloy composed, as Homberg scertained, of one part of silver and five of gold. He ept equal parts of gold and silver in gentle fusion for quarter of an hour, and found, on breaking the cruciле, two masses, the uppermost of which was pure silrer, the undermost the whole gold combined with $\frac{1}{6}$ of ilver. Silver, however, may be melted with gold in lmost any proportion; and if the proper precautions be mployed, the two metals remain combined together.

The alloy of gold and silver is harder and more sonorous than gold. Its hardness is a maximum when he alloy contains two parts of gold and one of ſilver ‡. The density of these metals is but little increased §; but he colour of the gold is much altered, even when the roportion of the silver is small; one part of silver pro-

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[*] *Pelletier*, *Ann. de Chim.* i. 73.

[†] *Ann. de Chim.* xiii. 110.

[‡] Muschenbroeck.

[§] Gellert.

duces a sensible whiteness in twenty parts of gold. The colour is not only pale, but it has also a very sensible greenish tinge, as if the light reflected by the silver passsed through a very thin covering of gold. This alloy being more fusible than gold, is employed to solder pieces of that metal together.

With Platinum.

2. When silver and platinum are fused together (for which a very strong heat is necessary), they form a mixture, not so ductile as silver, but harder and less white. The two metals are separated by keeping them for some time in the state of fusion; the platinum sinking to the bottom from its weight. This circumstance would induce one to suppose that there is very little affinity between them.

Affinities.

VI. The affinities of silver, and its oxides, are placed by Bergman in the following order:

SILVER.	OXIDE OF SILVER.
Lead,	Muriatic acid,
Copper,	Oxalic,
Mercury,	Sulphuric,
Bismuth,	Saclactic,
Tin,	Phosphoric,
Gold,	Sulphurous,
Antimony,	Nitric,
Iron,	Arsenic,
Manganese,	Fluoric,
Zinc,	Tartaric,
Arsenic,	Citric,
Nickel,	Lactic,
Platinum,	Acetic,
Sulphur,	Succinic,
Phosphorus.	Prussic,
	Carbonic.

SECT. IV.

OF MERCURY.

I. MERCURY, called also QUICKSILVER, was known in the remotest ages, and seems to have been employed by the ancients in gilding and in separating gold from other bodies, just as it is by the moderns.

Properties.

1. Its colour is white, and similar to that of silver; hence the names *hydrargyrum*, *argentum vivum*, *quicksilver*, by which it has been known in all ages. It has no taste nor smell. It possesses a good deal of brilliancy; and when its surface is not tarnished, makes a very good mirror.

2. Its specific gravity is 13.568[*].

3. At the common temperature of the atmosphere it is always in a state of fluidity. In this respect it differs from all other metals. But it becomes solid when exposed to a sufficient degree of cold. The temperature necessary for freezing this metal is —39°, as was ascertained by the experiments of Mr Macnab at Hudson's Bay. The congelation of mercury was accidentally discovered by the Petersburgh academicians in 1759. Taking the advantage of a very severe frost, they plunged a thermometer into a mixture of snow and salt, in order to ascertain the degree of cold thereby produced. Observing the mercury stationary, even

Point of congelation.

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[*] Cavendish and Brisson.

after it was removed from the mixture, they broke the bulb of the thermometer, and found the metal frozen into a solid mass. This experiment has been repeated very often since, especially in Britain*. Mercury contracts considerably at the instant of freezing; a circumstance which misled the philosophers who first witnessed its congelation. The mercury in their thermometers sunk so much before it froze, that they thought the cold to which it had been exposed much greater than it really was. It was in consequence of the rules laid down by Mr Cavendish, that Mr Macnab was enabled to ascertain the real freezing point of the metal.

4. Solid mercury may be subjected to the blows of a hammer, and may be extended without breaking. It is therefore malleable; but neither the degree of its malleability, nor its ductility, nor its tenacity, have been ascertained.

Boiling point.

5. Mercury boils when heated to 660°. It may therefore be totally evaporated, or distilled from one vessel into another. It is by distillation that mercury is purified from various metallic bodies with which it is often contaminated. The vapour of mercury is invisible and elastic like common air; like air, too, its elasticity is indefinitely increased by heat, so that it breaks through the strongest vessel. Geoffroy, at the desire of an alchymist, inclosed a quantity of it in an iron globe strongly secured by iron hoops, and put the apparatus into a furnace. Soon after the globe became red hot it burst with all the violence of a bomb, and the whole of the mercury was dissipated†.

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* The method of performing this experiment will be described in the Second Division of the First Part of this Work.

† Macquer's *Chemistry*.

Oxides.

II. Mercury is not altered by being kept under water. When exposed to the air, its surface is gradually tarnished, and covered with a black powder, owing to its combining with the oxygen of the atmosphere. But this change goes on very slowly, unless the mercury be either heated or agitated, by shaking it, for instance, in a large bottle full of air. By either of these processes the metal is converted into an oxide. By the last, into a black coloured oxide; and by the first, into a red coloured oxide. This metal does not seem to be capable of combustion; at least no method which I have hitherto tried to burn it has succeeded. It is the only metal I have hitherto had an opportunity of examining which may not, by peculiar management, be made to *burn*.

The oxides of mercury at present known are four in number.

Protoxide.

1. The protoxide was first described with accuracy by Boerhaave. He formed it by putting a little mercury into a bottle, and tying it to the spoke of a mill-wheel. By the constant agitation which it thus underwent, it was converted into a black powder, to which he gave the name of *ethiops per se*. This oxide is readily formed by agitating impure mercury in a phial. It is a black powder without any of the metallic lustre, has no taste, and is insoluble in water. According to the experiments of Fourcroy, it is composed of 96 parts of mercury and 4 of oxygen*. When this oxide is exposed to a strong heat, oxygen gas is emitted, and the mercury reduced to the metallic state. In a more mo-

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* *Jour. de Mines*, An. x. p. 283.

derate heat it combines with an additional dose of oxygen, and assumes a *red* colour.

Supposed deutoxide.

2. When mercury is dissolved in nitric acid without the assistance of heat, and the acid is made to take up as much mercury as possible, it has been demonstrated, by the experiments of Mr Chenevix, that it combines in that case with 10.7 *per cent.* of oxygen*. Of course an oxide is formed, composed of 89.3 mercury and 10.7 oxygen. This is the *deutoxide* of mercury. This oxide cannot be separated completely from the acid which holds it in solution without undergoing a change in its composition; of course we are at present ignorant of its *colour* and other properties. Indeed it is very probable that it is the same with the black oxide just described under the name of *protoxide*; but this has not yet been proved in a satisfactory manner.

Red oxide.

3. When mercury, or its protoxide, is exposed to a heat of about 600°, it combines with additional oxygen, assumes a red colour, and is converted into an oxide, which, in the present state of our knowledge, we must consider as a *tritoxide*. This oxide may be formed two different ways: 1. By putting a little mercury into a flat bottomed glass bottle or matrass, the neck of which is drawn out into a very narrow tube, putting the matrass into a sand bath, and keeping it constantly at the boiling point. The height of the matrass, and the smallness of its mouth, prevents the mercury from making its escape, while it affords free access to the air. The surface of the mercury becomes gradually black, and then red, by combining with the oxygen of the air:

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* *Phil. Trans.* 1802.

and at the end of several months, the whole is converted into a red powder, or rather into small crystals, of a very deep red colour. The oxide, when thus obtained, was formerly called *precipitate per se.* 2. When mercury is dissolved in nitric acid, evaporated to dryness, and then exposed to a pretty strong heat in a porcelain cup, it assumes, when triturated, a brilliant red colour. The powder thus obtained was formerly called *red precipitate,* and possesses exactly the properties of the oxide obtained by the former process.

This oxide has an acrid and disagreeable taste, possessing poisonous qualities, and acts as an escharotic when applied to any part of the skin. It is somewhat soluble in water. When triturated with mercury it gives out part of its oxygen, and the whole mixture is converted into protoxide or black oxide of mercury. When heated along with zinc or tin filings, it sets these metals on fire. According to Fourcroy, it is composed of 92 parts of mercury and 8 of oxygen *. But the analysis of Mr Chenevix, to be described hereafter, gives, for the proportion of its component parts, 85 parts of mercury and 15 parts of oxygen.

Seldom pure.

Were this the proper place, I could relate several experiments, which demonstrate that the red oxide of mercury, prepared in the usual way, is not pure, but always contains a portion of nitric acid. If we dissolve it in muriatic acid, and precipitate it again, it falls in the state of a white powder, and retains a portion of muriatic acid. It was in this state that it was examined by Chenevix. The difficulty of the procuring this

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* *Jour. de Mines,* An. x. p. 283.

oxide in a state of purity, and the uncertainty respecting the proportion of acid which it retains, may, in some measure, account for the different results obtained by different chemists in their attempts to ascertain its proportions.

Peroxide.

4. Fourcroy has observed, that when oxy-muriatic acid gas is made to pass through the red oxide of mercury, it combines with an additional dose of oxygen, and is converted into a peroxide; but as this peroxide cannot be procured in a separate state, we are ignorant of its properties.

Combination with combustibles.

III. Mercury does not combine with carbon nor hydrogen; but it unites readily with sulphur and with phosphorus.

Black sulphuret.

1. When two parts of sulphur and one of mercury are triturated together in a mortar, the mercury gradually disappears, and the whole assumes the form of a black powder, formerly called *ethiops mineral.* It is scarcely possible by this process to combine the sulphur and mercury so completely, that small globules of the metal may not be detected by a microscope. When mercury is added slowly to its own weight of melted sulphur, and the mixture is constantly stirred, the same black compound is formed.

Fourcroy had suggested, that in this compound the mercury is in the state of black oxide, absorbing the necessary portion of oxygen from the atmosphere during its combination with the sulphur *. But the late experiments of Proust have shewn that this is not the case †. Berthollet has made it probable that æthiops mineral

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* Fourcroy, v. 298.

† *Jour de Phys.* liii. 92.

contains sulphureted hydrogen. Hence we must consider it as composed of three ingredients, namely, *mercury*, *sulphur*, and *sulphureted hydrogen*. Such compounds are at present denominated by chemists hydrogenous sulphurets. Ethiops mineral of course is a hydrogenous sulphuret of mercury.

When this substance is heated, part of the sulphur is dissipated, and the compound assumes a deep violet colour.

Cinnabar.

2. When heated red hot, it sublimes; and if a proper vessel be placed to receive it, a cake is obtained of a fine red colour. This cake was formerly called *cinnabar;* and when reduced to a fine powder, is well known in commerce under the name of *vermilion* *. It has been hitherto supposed a compound of the oxide of mercury and sulphur. But the experiments of Proust have demonstrated that the mercury which it contains is in the metallic state. According to that very accurate chemist, it is composed of 85 parts of mercury and 15 of sulphur †. It is therefore *sulphuret of mercury*.

The sulphuret of mercury has a scarlet colour, more or less beautiful, according to the mode of preparing it. Its specific gravity is about 10. It is tasteless, insoluble in water, and in muriatic acid, and not altered by exposure to the air. When heated sufficiently it takes fire, and burns with a blue flame. When mixed with

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* The word *vermilion* is derived from the French word *vermeil*, which comes from *vermiculus* or *vermiculum ;* names given in the middle ages to the *kermes* or *coccus ilicis*, well known as a red dye. *Vermilion* originally signified the red dye of the kermes. See *Beckmann*'s *History of Discoveries*, ii. 180.

† *Jour. de Phys.* liii. 92.

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half its weight of iron filings, and distilled in a stone ware retort, the sulphur combines with the iron, and the mercury passes into the receiver, which ought to contain water. By this process mercury may be obtained in a state of purity. The use of sulphuret of mercury as a paint is well known.

Cinnabar may be prepared by various other processes. One of the simplest of these is the following, lately discovered by Mr Kirchoff. When 300 grains of mercury and 68 of sulphur, with a few drops of solution of potass to moisten them, are triturated for some time in a porcelain cup by means of a glass pestle, ethiops mineral is produced. Add to this 160 grains of potass, dissolved in as much water. Heat the vessel containing the ingredients over the flame of a candle, and continue the trituration without interruption during the heating. In proportion as the liquid evaporates, add clear water from time to time, so that the oxide may be constantly covered to the depth of near an inch. The trituration must be continued about two hours; at the end of which time the mixture begins to change from its original black colour to a brown, which usually happens when a large part of the fluid is evaporated. It then passes very rapidly to a red. No more water is to be added; but the trituration is to be continued without interruption. When the mass has acquired the consistence of a gelly, the red colour becomes more and more bright, with an incredible degree of quickness. The instant the colour has acquired its utmost beauty, the heat must be withdrawn, otherwise the red passes to a dirty brown. Count de Moussin Pouschkin has discovered, that its passing to a brown colour may be prevented by taking it from the fire as soon as it has acquired a red colour, and placing it for two or three days in a gentle heat, taking care to add a few drops of water, and to agitate the mixture from time to time. During this exposure, the red colour gradually improves, and at last becomes excellent. He discovered also, that when this sulphuret is exposed to a strong heat, it becomes instantly brown, and then passes into a dark violet; when taken from the fire it passes instantly to a beautiful carmine red *.

Phosphuret.

3. Mr Pelletier, after several unsuccessful attempts to combine phosphorus and mercury, at last succeeded by distilling a mixture of red oxide of mercury and phosphorus. Part of the phosphorus combined with the oxygen of the oxid, and was converted into an acid; the rest combined with the mercury. He observed that the mercury was converted into a black powder before it combined with the phosphorus. On making the experiment, I found that phosphorus combines very readily with the black oxide of mercury, when melted along with it in a retort filled with hydrogen gas to prevent the combustion of the phosphorus. As Pelletier could not succeed in his attempts to combine phosphorus with mercury in its metallic state, we must conclude that it is not with mercury, but with the black oxide of mercury, that the phosphorus combines. The compound therefore is not *phosphuret of mercury*, but *black phosphureted oxide of mercury*.

It is of a black colour, of a pretty solid consistence, and capable of being cut with a knife. When exposed to the air, it exhales vapours of phosphorus †.

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* Nicholson's *Journal*, ii. 1.

† *Ann. de Chim.* xiii. 122.

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IV. Mercury does not combine with the simple incombustibles.

Amalgams

V. Mercury combines with the greater number of metals. These combinations are known in chemistry by the name of *amalgams* *.

Of Gold,

1. The amalgam of gold is formed very readily, because there is a very strong affinity between the two metals. If a bit of gold be dipped into mercury, its surface, by combining with mercury, becomes as white as silver. The easiest way of forming this amalgam is to throw small pieces of red hot gold into mercury. The proportions of the ingredients are not determinable, because the amalgam has an affinity both for the gold and the mercury; in consequence of which they combine in any proportion. This amalgam is white with a shade of yellow; and when composed of six parts of mercury and one of gold, it may be obtained crystallized in four-sided prisms. It melts at a moderate temperature; and when heated sufficiently, the mercury evaporates, and leaves the gold in a state of purity. It is much used in gilding. The amalgam, composed of ten parts of mercury and one of gold, is spread upon the metal which is to be gilt; and then, by the application of a gentle and equal heat, the mercury is driven off and the gold left adhering to the metallic surface: this surface is then rubbed with a brass wire brush under water, and afterwards burnished †.

Platinum,

2. Dr Lewis attempted to form an amalgam of platinum, but hardly succeeded after a labour which last-

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* This word is supposed to be derived from *αμα* and *γαμεω*; of course t signifies literally *intermarriage*.

† Gellert's *Metallurgic Chemistry*, 375.

ed for several weeks. Guyton Morveau succeeded by means of heat. He fixed a small cylinder of platinum at the bottom of a tall glass vessel, and covered it with mercury. The vessel was then placed in a sand-bath, and the mercury kept constantly boiling. The mercury gradually combined with the platinum; the weight of the cylinder was doubled, and it became brittle. When heated strongly, the mercury evaporated, and left the platinum partly oxidated. It is remarkable that the platinum, notwithstanding its superior specific gravity, always swam upon the surface of the mercury, so that Morveau was under the necessity of fixing it down *.

Silver

3. The amalgam of silver is made in the same manner as that of gold, and with equal ease. It forms dentritical crystals, which, according to the Dijon academicians, contain eight parts of mercury and one of silver. It is of a white colour, and is always of a soft consistence. Its specific gravity is greater than the mean of the two metals. Gellert has even remarked that, when thrown into pure mercury, it sinks to the bottom of that liquid †. When heated sufficiently, the mercury is volatilized, and the silver remains behind pure.

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* *Ann. de Chim.* xxv. 12.—This was doubtless owing to the strong cohesion which exists between the particles of mercury. If you lay a large mass of platinum upon the surface of mercury, it sinks directly on account of its weight; but a small slip (a platinum wire for instance) swims, being unable to overcome the cohesion of the mercury. However, if you plunge it to the bottom, it remains there in consequence of its superior weight. If heat be now applied to the bottom of the vessel, the wire comes again to the surface, being buoyed up by the hot mercury, to which it has begun to adhere. These facts explain the seeming anomaly observed by Morveau.

† Gellert's *Metallurgic Chemistry*, 142.

VI. The affinities of mercury as ascertained by Morveau, and of its oxides as exhibited by Bergman, are in the following order:

Affinities.

MERCURY.	OXIDE OF MERCURY.
Gold,	Muriatic acid,
Silver,	Oxalic,
Tin,	Succinic,
Lead,	Arsenic,
Bismuth,	Phosphoric,
Platinum,	Sulphuric,
Zinc,	Saclactic,
Copper,	Tartaric,
Antimony,	Citric,
Arsenic,	Sulphurous,
Iron.	Nitric,
	Fluoric,
	Acetic,
	Boracic,
	Prussic,
	Carbonic,

SECT. V.

OF COPPER.

I. If we except gold and silver, copper seems to have been more early known than any other metal. In the first ages of the world, before the method of working iron was discovered, copper was the principal ingredient in all domestic utensils and instruments of war. Even during the Trojan war, as we learn from Homer, the combatants had no other armour but what was made of bronze, which is a mixture of *copper* and *tin*. The word *copper* is derived from the island of Cyprus, where it was first discovered, or at least wrought to any extent, by the Greeks.

Properties of copper.

1. This metal is of a fine red colour, and has a great deal of brilliancy. Its taste is styptic and nauseous; and the hands, when rubbed for some time on it, acquire a peculiar and disagreeable odour.

2. Its hardness is 7.5. Its specific gravity, when melted, is 8.667; but after being hammered it is 8.9.

3. Its malleability is great; it may be hammered out into leaves so thin as to be blown about by the slightest breeze. Its ductility is also considerable. Its tenacity is such, that a copper wire 0.078 inch in diameter is capable of supporting 302.26 lbs. avoirdupois without breaking *.

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* Sickingen, *Ann. de Chim.* xxv. 9.

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4. When heated to the temperature of 27° Wedgewood, or, according to the calculation of Mortimer*, to 1450° Fahrenheit, it melts; and if the heat be increased, it evaporates in visible fumes. When allowed to cool slowly, it assumes a crystalline form. The Abbé Mongez, to whom we owe many valuable experiments on the crystallization of metals, obtained it in quadrangular pyramids, often inserted into one another.

II. Copper is not altered by water: it is incapable of decomposing it even at a red heat, unless air have free access to it at the same time; in that case the surface of the metal becomes oxidated. Every one must have remarked, that when water is kept in a copper vessel, a green crust of *verdegris*, as it is called, is formed on that part of the vessel which is in contact with the surface of the water.

Oxides.

When copper is exposed to the air, its surface is gradually tarnished; it becomes brown, and is at last covered with a dark green crust. This crust consists of oxide of copper combined with carbonic acid gas. At the common temperature of the air, this oxidation of copper goes on but slowly; but when a plate of metal is heated red hot, it is covered in a few minutes with a crust of oxide, which separates spontaneously in small scales when the plate is allowed to cool. The copper-plate contracts considerably in cooling, but the crust of oxide contracts but very little; it is therefore broken to pieces and thrown off, when the plate contracts under it. Any quantity of this oxide may be obtained by heating a plate of copper and plunging it alternately in-

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* *Phil. Trans.* xliv. 672.

to cold water. The scales fall down to the bottom of the water.

In a violent heat, or when copper is exposed to a stream of oxygen and hydrogen gas, the metal takes fire and burns with great brilliancy, emitting a lively green light of such intensity, that the eye can scarcely bear the glare. The product is an oxide of copper.

There are two oxides of copper at present known; and it does not appear that the metal is capable of being exhibited in combination with more than two doses of oxygen. The *protoxide* is of a fine *orange* colour; but the *peroxide* is *black*, though in combination it assumes various shades of blue, green, and brown.

Protoxide.

1. The protoxide of copper was first observed by Proust; but we are indebted to Mr Chenevix, who found it native in Cornwall, for the investigation of its properties. It may be prepared by mixing together 57.5 parts of black oxide of copper, and 50 parts of copper reduced to a fine powder by precipitating it from muriatic acid by an iron plate. This mixture is to be triturated in a mortar, and put with muriatic acid into a well stopped phial. Heat is disengaged, and almost all the copper is dissolved. When potass is dropt into this solution, the orange oxide of copper is precipitated. But the easiest process is to dissolve any quantity of copper in muriatic acid by means of heat. The green liquid thus obtained is to be put into a phial, together with some pieces of rolled copper, and the whole is to be corked up closely. The green colour gradually disappears, the liquid becomes dark brown and opaque, and a number of dirty white crystals, like grains of sand, are gradually deposited. When this liquid, or

the crystals, are thrown into a solution of potass, the orange coloured oxide precipitates in abundance.

This oxide is composed of 88.5 parts of copper and 11.5 oxygen*. It attracts oxygen with such avidity, that it can scarcely be dried without becoming bluish green, at least on the surface; but when once dry, it retains its colour pretty well.

Peroxide.

2. The peroxide of copper is easily procured pure from the scales which are formed upon the surface of red hot copper. These scales have a violet red colour, owing to the presence of a little metallic copper upon their under surface; but when kept for some time red hot in an open vessel, they become black, and are then pure peroxide of copper. The same oxide may be obtained by dissolving copper in sulphuric or nitric acid, precipitating by means of potass, and then heating the precipitate sufficiently to drive off any water which it may retain.

The peroxide of copper is composed of 80 parts of copper and 20 of oxygen†. When mixed with somewhat less than its own weight of copper in powder, and heated to redness, the whole is converted into protoxide.

The oxides of copper are easily reduced to the metallic state when heated along with charcoal, oils, or other fatty bodies; and even with some of the metals, especially zinc.

3. When copper is dissolved in nitric acid, and a sufficient quantity of potass added to the solution, a blue

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* Chenevix, *Phil. Trans.* 1801, p. 227.

† *Ann. de Chim.* xxxii. 26.

Hydrat.

powder falls to the bottom, which was formerly considered as a peculiar oxide of copper, and accordingly called *blue oxide of copper*. But Mr Proust has shown that it is nothing else than the black oxide combined with water, and has therefore called it *hydrat of copper*. When distilled, 100 parts of it yield 25 parts of water, and there remain behind 75 parts of black oxide.

Carbonat.

When this blue powder is exposed moist to the atmosphere, it gradually becomes green. This was formerly supposed to be owing to the absorption of oxygen; accordingly the green powder was called *green oxide of copper*. But Mr Proust has shown that this change is not owing to the absorption of oxygen, but to the combination of the black oxide of copper with carbonic acid.

Union with combustibles.

III. Copper has never been combined with carbon nor hydrogen; but it combines readily with sulphur and phosphorus, and forms with them compounds called *sulphuret* and *phosphuret of copper*.

Sulphuret.

1. When equal parts of sulphur and copper are stratified alternately in a crucible, they melt, and combine at a red heat. Sulphuret of copper, thus obtained, is a brittle mass, of a black or very deep blue grey colour, much more fusible than copper, and composed, according to the experiments of Mr Proust, of 78 parts of copper and 22 of sulphur *. The same compound may be formed by mixing copper filings and sulphur together, and making them into a paste with water, or even by merely mixing them together without any water, and allowing them to remain a sufficient time exposed to the air, as I have ascertained by experiment.

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* *Ann. de Chim.* xxxviii. 172.

If eight parts by weight of copper filings, mixed with three parts of flowers of sulphur, be put into a glass receiver, and placed upon burning coals, the mixture first melts, then a kind of explosion takes place; it becomes red hot, and when taken from the fire, continues to glow for some time like a live coal. If we now examine it, we find it converted into *sulphuret of copper*. This curious experiment was first made by the associated Dutch chemists Deiman, Troostwyk, Nieuwland, Bondt, and Laurenburg, in 1793*. They found that the combustion succeeds best when the substances are mixed in the proportions mentioned above: that it succeeds equally, however pure and dry the sulphur and copper be, and whatever air be present in the glass vessel, whether common air, or oxygen gas, or hydrogen, or azotic gas, or even when the receiver is filled with water or mercury. This experiment has excited great attention, and has been very often repeated; because it is the only instance known of apparent combustion without the presence of oxygen. The different attempts to explain it will be considered in a succeeding Chapter.

Supersulphuret.

2. Mr Proust has shown that the sulphuret of copper is capable of combining with an additional dose of sulphur, and of forming a new compound which may be called *supersulphuret of copper*. It is brittle, has a yellow colour, and a metallic lustre, and is found native abundantly, being well known to mineralogists by the name of *copper pyrites* †.

Phosphuret.

3. Mr Pelletier formed *phosphuret of copper* by melt-

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* *Jour. de Min.* N° 2. 85.

† *Jour. de Phys.* liii. 95.

Phosphuris.

ing together 16 parts of copper, 16 parts of phosphoric glass, and one part of charcoal*. Margraf was the first person who formed this phosphuret. His method was to distil phosphorus and oxide of copper together. It is formed most easily by projecting phosphorus into red hot copper. It is of a white colour; and, according to Pelletier, is composed of 20 parts of phosphorus and 80 of copper †. This phosphuret is harder than iron: It is not ductile, and yet cannot easily be pulverised. Its specific gravity is 7.1220. It crystallizes in four-sided prisms ‡. It is much more fusible than copper. When exposed to the air, it loses its lustre, becomes black, falls to pieces, the copper is oxidated, and the phosphorus converted into phosphoric acid. When heated sufficiently, the phosphorus burns, and leaves the copper under the form of black scoriæ §.

IV. Copper is not capable of combining with azote. Muriatic acid gas readily converts it into an oxide, with which it enters into combination.

Alloys with

V. Copper is capable of combining with most of the metals; and some of its alloys are of very great utility.

Gold,

1. The alloy of gold and copper is easily formed by melting the two metals together. This alloy is much used, because copper has the property of increasing the hardness of gold without injuring its colour. Muschenbroeck has ascertained, that the hardness of this alloy is a maximum when it is composed of seven parts of gold and one of copper. The gold coin both in Britain and

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* *Ann. de Chim.* i. 74.

† *Ibid.* xiii. 3.

‡ Sage, *Jour. de Phys.* xxxviii. 468.

§ Fourcroy, vi. 252.

Chap. IV.

France is an alloy containing eleven parts of gold and one of copper. Its specific gravity is considerably above the mean; consequently the density of the metals is increased by alloying them together. It ought to be 17.153, but it actually is 17.486; so that the density is increased $\frac{1}{48}$ part *. This alloy being more fusible than gold, is employed as a solder to join pieces of that metal together.

Platinum,

2. Platinum may be alloyed with copper by fusion, but a strong heat is necessary. The alloy is ductile, hard, takes a fine polish, and is not liable to tarnish. This alloy has been employed with advantage for composing the mirrors of reflecting telescopes.

Silver,

3. Silver is easily alloyed with copper by fusion. This alloy is harder and more sonorous than silver, and yet the density of the metals is diminished. Thus when 137 parts of silver and 7 of copper are alloyed together, the specific gravity ought to be 10.3016, but it actually is 10.1752; consequently the bulk of the two metals is increased by alloying them together about $\frac{1}{81}$ part †. When the proportion of copper is small, the colour of the silver is not altered. The silver coin of this country is composed of 1 part of copper and 15 of silver; that of France of 7 parts of copper and 137 of silver, or 1 part copper and 19.57 silver ‡. The French silver coin therefore is purer than the British.

Mercury.

4. The amalgam of copper cannot be formed by simply mixing that metal with mercury, nor even by the application of heat; because the heat necessary to melt copper sublimes mercury. Dr Lewis has given us se-

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* Brisson.

† Hauy, *Jour. de Min.* An. v. p. 471.

‡ *Ibid.*

veral processes for forming this amalgam. One of the simplest is to triturate mercury with a quantity of common salt and verdigris; a substance composed of oxide of copper and vinegar. The theory of this process is not very obvious. It may be formed also by keeping plates of copper in a solution of mercury in nitric acid. The plate is soon impregnated with mercury. The amalgam of copper is of a reddish white colour, and so soft at first that it takes the most delicate impressions; but it soon becomes harder when exposed to the air. It is easily decomposed by heat; the mercury evaporates, and leaves the copper.

Affinities.

VI. The affinities of copper and its oxides are exhibited by Bergman in the following order:

Copper.	Oxide of Copper.
Gold,	Oxalic acid,
Silver,	Tartaric,
Arsenic,	Muriatic,
Iron,	Sulphuric,
Manganese,	Saclactic,
Zinc,	Nitric,
Antimony,	Arsenic,
Platinum,	Phosphoric,
Tin,	Succinic,
Lead,	Fluoric,
Nickel,	Citric,
Bismuth,	Lactic,
Cobalt,	Acetic,
Mercury,	Boracic,
Sulphur,	Prussic,
Phosphorus.	Carbonic.

SECT. VI.

OF IRON.

History.

I. Iron, the most abundant and most useful of all the metals, was neither known so early, nor wrought so easily, as gold, silver, and copper. For its discovery we must have recourse to the nations of the East, among whom, indeed, almost all the arts and sciences first sprung up. The writings of Moses (who was born about 1635 years before Christ) furnish us with the amplest proof at how early a period it was known in Egypt and Phœnicia. He mentions furnaces for working iron *, ores from which it was extracted †; and tells us, that swords ‡, knives §, axes‖, and tools for cutting stones ¶, were then made of that metal. How many ages before the birth of Moses iron must have been discovered in these countries, we may perhaps conceive, if we reflect, that the knowledge of iron was brought over from Phrygia to Greece by the Dactyli**, who settled in Crete during the reign of Minos I. about 1431 years before Christ; yet during the Trojan war, which happened 200 years after that period, iron was in such high estimation, that Achilles proposed a ball of it as one of his prizes during the games which he celebrated in honour of Patroclus. At that period none

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* Deut. iv. 20.

† Ibid. viii. 9.

‡ Numb. xxxv. 16.

§ Levit. i. 17.

‖ Deut. xviii. 5.

¶ Ibid. xxvii. 5.

** Hesiod, as quoted by Pliny, lib. vii. c. 57.

of their weapons were formed of iron. Now if the Greeks in 200 years had made so little progress in an art which they learned from others, how long must it have taken the Egyptians, Phrygians, Chalybes, or whatever nation first discovered the art of working iron, to have made that progress in it which we find they had done in the days of Moses?

Properties of iron.

1. Iron is of a bluish white colour; and when polished, has a great deal of brilliancy. It has a styptic taste, and emits a smell when rubbed.

2. Its hardness is 9. Its specific gravity varies from 7.6 to 7.8.

3. It is attracted by the magnet or loadstone, and is itself the substance which constitutes the loadstone. But when iron is perfectly pure, it retains the magnetic virtue a very short time.

4. It is malleable in every temperature, and its malleability increases in proportion as the temperature augments; but it cannot be hammered out nearly so thin as gold or silver, or even copper. Its ductility, however, is more perfect; for it may be drawn out into wire as fine at least as a human hair. Its tenacity is such, that an iron wire 0.078 of an inch in diameter is capable of supporting 549.25 lbs. avoirdupois without breaking *.

5. When heated to about 158° Wedgewood, as Sir George M'Kenzie has ascertained †, it melts. This temperature being nearly the highest to which it can be raised, it has been impossible to ascertain the point at which this melted metal begins to boil and to evaporate. Neither has the form of its crystals been examined: but

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* Sickingen, *Ann. de Chim.* xxv. 9.

† Nicholson's *Journal*, iv. 109.

it is well known that the texture of iron is fibrous; that is, it appears when broken to be composed of a number of fibres or strings bundled together.

Combination with oxygen.

II. When exposed to the air, its surface is soon tarnished, and it is gradually changed into a brown or yellow powder, well known under the name of *ruſt*. This change takes place more rapidly if the atmosphere be moist. It is occasioned by the gradual combination of the iron with the oxygen of the atmosphere, for which it has a very strong affinity.

Decomposes water.

1. When iron filings are kept in water, provided the temperature be not under 70°, they are gradually converted into a black powder, while a quantity of hydrogen gas is emitted. This is occasioned by the slow decomposition of the water The iron combines with its oxygen, while the hydrogen makes its escape under the form of gas *. If the water be made to boil, it is decomposed much more speedily. Very perceptible bubbles of hydrogen gas rise from the iron, and may be collected at the top of the vessel. This experiment may be made in a glass retort. The iron filings are to be put in first, and then the retort is to be completely filled with water, and its beak plunged into an open vessel of water. The retort is then to be made to boil by applying under it a lamp.

If the steam of water be made to pass through a red hot iron tube, it is decomposed instantly. The oxygen combines with the iron, and the hydrogen gas passes through the tube, and may be collected in proper vessels. This is one of the easiest methods of procuring pure hydrogen gas.

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* This fact was known to Bergman (*Opusc.* iii. 95.), and to Scheele (*on Fire*, p. 180.); but it was first explained by Lavoisier.

Combustible.

2. These facts are sufficient to show that iron has a strong affinity for oxygen, since it is capable of taking it from air and water. It is capable also of taking fire and burning with great rapidity. Twist a small iron wire into the form of a cork screw, by rolling it round a cylinder; fix one end of it into a cork, and attach to the other a small bit of cotton thread dipt in melted tallow. Set fire to the cotton, and plunge it while burning into a jar filled with oxygen gas. The wire catches fire from the cotton and burns with great brilliancy, emitting very vivid sparks in all directions. For this very splendid experiment we are indebted to Dr Ingenhousz. During this combustion the iron combines with oxygen, and is converted into an oxide.

Oxides two;

Mr Proust has proved that there are only two oxides of iron; the protoxide has usually a black colour, but the peroxide is red.

Protoxide.

3. The protoxide of iron may be obtained by four different processes. 1. By keeping iron filings a sufficient time in water at the temperature of 70°. The oxide thus formed is a black powder, formerly much used in medicine under the name of *martial ethiops*, and seems to have been first examined by Lemeri *. 2. By making steam pass through a red hot iron tube. The iron is changed into a brilliant black brittle substance, which when pounded assumes the appearance of martial ethiops. This experiment was first made by Lavoisier.

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* The best process is that of De Roover. He exposes a paste formed of iron filings and water to the open air, in a stone ware vessel; the paste becomes hot, and the water disappears. It is then moistened again, and the process repeated till the whole is oxydized. The mass is then pounded, and the powder is heated in an iron vessel till it is perfectly dry, stirring it constantly. See *Ann. de. Chim.* xliv. 329.

3. By burning iron wire in oxygen gas. The wire as it burns is melted, and falls in drops to the bottom of the vessel, which ought to be covered with water, and to be of copper. These metallic drops are brittle, very hard, and blackish, but retain the metallic lustre. They were examined by Lavoisier, and found precisely the same with martial ethiops [*]. They owe their lustre to the fusion which they underwent. 4. By dissolving iron in sulphuric acid, and pouring potass into the solution. A green powder falls to the bottom, which assumes the appearance of martial ethiops when dried quickly in close vessels. This first oxide of iron, however formed, is always composed of 73 parts of iron and 27 of oxygen, as Lavoisier and Proust have demonstrated [†]. It is attracted by the magnet, and is often itself magnetic [‡]. It is capable of crystallizing, and is often found native in that state.

Peroxide.

4. The peroxide or *red* oxide of iron may be formed by keeping iron filings red hot in an open vessel, and agitating them constantly till they are converted into a dark red powder. This oxide was formerly called *saffron of Mars.* Common rust of iron is merely this oxide combined with carbonic acid gas. The red oxide may be obtained also by exposing for a long time a diluted solution of iron in sulphuric acid to the atmosphere, and then dropping into it an alkali, by which the oxide is precipitated. This oxide is also found native in great abundance. Proust proved it to be composed of 48 parts of oxygen and 52 of iron [§]. Consequently the protoxide, when converted into red oxide, absorbs

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[*] *Ann. de Chim.* i. 19.

[†] Ibid. and xxiii. 87.

[‡] Bergman, iii. 102.

[§] *Ann. de Chim.* xxiii. 87.

0.40 of oxygen; or, which is the same thing, the red oxide is composed of 66.5 parts of black oxide and 33.5 parts of oxygen. One hundred parts of iron, when converted into a protoxide, absorb 37 parts of oxygen, and the oxide weighs 137; when converted into peroxide, it absorbs 52 additional parts of oxygen, and the oxide weighs 189.

The peroxide cannot be decomposed by heat; but when heated along with its own weight of iron filings, the whole, as Vauquelin first observed, is converted into black oxide. The reason of this conversion is evident: The 100 parts of peroxide are composed of 52 parts of iron, combined with two different doses of oxygen: 1. With 14 parts, which, with the iron, make 66 of protoxide: 2. With 34 parts, which, with the protoxide, make up the 100 parts of peroxide. Now, the first of these doses has a much greater affinity for the iron than the second has. Consequently the 34 parts of oxygen, which constitute the second dose, being retained by a weak affinity, are easily abstracted by the 100 parts of pure iron; and combining with the iron, the whole almost is converted into black oxide: for 100 parts of iron, to be converted into black oxide, require only 37 parts of oxygen *.

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* Mr Chenevix, in his excellent paper on the *arseniats of copper*, has given it as his opinion, that iron is susceptible of four different degrees of oxydizement. The first oxide, according to him, is of a *white* colour, the second is *green*, the third *black*, and the fourth *red*. His opinion is chiefly founded upon the different colours which minerals containing iron are observed to possess; namely, *white* (or colourless), *green*, *black*, *red*, *brown*, and *blue*. But it is more likely that these different colours are the results of the various combinations into which the two oxides of iron enter. Difference of colour is a very uncertain mark of difference

The peroxide of iron is not magnetic. It is converted into black oxide by sulphureted hydrogen gas and many other substances; which deprive it of the second dose of oxygen, for which they have a stronger affinity, though they are incapable of decomposing the protoxide.

Union with combustibles.

III. Iron is capable of combining with all the simple combustible bodies.

1. Hydrogen, indeed, has never been united to it in a solid state; but when hydrogen gas is obtained by the solution of iron filings in diluted sulphuric acid, it carries along with it a little of the iron, which is gradually deposited in the form of a brown powder on the sides of the jars in which the hydrogen gas is confined. With sulphur, phosphorus, and carbon, iron forms compounds known by the name of *sulphuret*, *phosphuret*, and *carburet* of iron.

Sulphuret.

2. Sulphuret of iron may be formed by melting together in a crucible equal parts of iron filings and powdered sulphur. It is of a black or very deep grey colour, brittle, and remarkably hard. When reduced to

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in the proportion of oxygen combined with a metal. The black oxide of iron dissolves in acids without effervescence, and therefore without any sensible change in the proportion of its oxygen; yet with potass it gives uniformly a greenish-coloured precipitate, which becomes deeper and deeper coloured when exposed to the light; and no difference is observable when the experiments are performed *in vacuo*, or in a close vessel under water. The same oxide yields with phosphoric acid a white precipitate, which becomes blue when dried in the open air; and with prussic acid, a white precipitate, which retains its colour as long as the contact of air is withheld. At any rate no person has hitherto succeeded in obtaining a *white* or a *green* oxide of iron containing a different proportion of oxygen from the black; consequently in the present state of our knowledge, we must consider them all as the same protoxide.

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powder, and moistened with water, the sulphur is gradually converted into sulphuric acid by absorbing oxygen, while at the same time the iron is oxidized. The same compound may be formed by mixing together three parts (by weight) of iron filings, and one part of powdered sulphur, and putting the mixture in a glass vessel upon burning coals. This mixture, as the Dutch chemists first ascertained, melts, and burns without the presence of air, just as copper filings and sulphur, though not with such brilliancy *. But the combustion, as I have observed, is remarkably brilliant, and even accompanied by an explosion, if a considerable mixture of iron filings and sulphur be melted together in a covered crucible. It continues much longer than that of copper and sulphur.

If equal quantities of iron filings and sulphur be mixed together, and formed into a paste with water, the sulphur decomposes the water, and absorbs oxygen so rapidly that the mixture sometimes takes fire, even though it be buried under ground. This phenomenon was first discovered by Lemeri; and it was considered by him as affording an explanation of the origin of volcanoes †.

From the experiments of Proust it appears, that sulphuret of iron is composed of 60 parts of sulphur and
40 iron

100 ‡

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* *Jour. de Min.* N° ii. 91.

† When this experiment was repeated by Bucquet, it did not succeed. Fourcroy's *Systeme des Connais. Chim.* vi. 171.

‡ *Jour de Phys.* liii. 89.

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Supersulphuret or pyrites.

3. Iron is capable of combining with an additional doze of sulphur, and of forming a new compound, which may be called *supersulphuret of iron*. This compound is found native in great abundance, and has been long known by the name of pyrites. This substance is of a yellow colour, and has the metallic lustre. It is brittle, and sufficiently hard to strike fire with steel. Its specific gravity is about 4.5. It usually crystallizes in cubes. When heated it is decomposed. In the open air, the sulphur takes fire in close vessels filled with charcoal; part of the sulphur is volatilized; and a black substance remains, retaining the original form of the mineral, but falling to powder on the slightest touch. Mr Proust has demonstrated that this black substance is common sulphuret of iron. Pyrites, according to him, when thus treated, gives out 0.20 parts of sulphur, and 0.80 parts of sulphuret remain behind*. Hence pyrites is composed of 80 sulphuret of iron

20 sulphur

100

It therefore contains no less than 0.68 parts of its weight of sulphur. Mr Proust has observed, that it may be easily converted into common sulphuret by heating it along with some iron filings. This would be the most commodious method of procuring sulphuret of iron.

I have sometimes succeeded in forming pyrites artificially. Let equal quantities of iron filings and sulphur be put into a crucible furnished with a cover, and luted with clay to prevent the access of air. Apply a

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* *Jour. de Phys.* liii. 89.

sudden heat, to bring the mixture to fusion pretty rapidly. An explosion takes place, which drives up the cover of the crucible a little. When this happens, take the crucible off the fire and let it cool, without removing the cover. The surface of the mixture is often found covered with pyrites, sometimes even crystallized.

Phosphuret.

4. Phosphuret of iron may be formed by fusing in a crucible 16 parts of phosphoric glass, 16 parts of iron, and half a part of charcoal powder. It is magnetic, very brittle, and appears white when broken. When exposed to a strong heat, it melts, and the phosphorus is dissipated *. It may be formed also by melting together equal parts of phosphoric glass and iron filings. Part of the iron combines with the oxygen of the phosphoric glass, and is vitrified; the rest forms the phosphuret, which sinks to the bottom of the crucible. It may be formed also by dropping small bits of phosphorus into iron filings heated red hot †. The proportions of the ingredients of this phosphuret have not yet been determined. It was first discovered and examined by Bergman, who took it for a new metal, and gave it the name of *siderum*.

History of its discovery.

There is a particular kind of iron, known by the name of *cold short iron*, because it is brittle when cold, though it be malleable when hot. Bergman ‡ was employed at Upsal in examining the cause of this property, while Meyer § was occupied at Stetin with the same investigation; and both of them discovered, nearly at the same time, that, by means of sulphuric acid, a white

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[*] Pelletier, *Ann. de Chim.* i. 105.

[†] Id. *Ibid.* xiii 113.

[‡] *Opusc.* iii. 109.

[§] *Schriften der Berliner Gesellsch. Naturf. Freunde*, 1780, ii. 334. and iii. 380.

powder could be separated from this kind of iron, which by the usual process they converted into a metal of a dark steel grey, exceedingly brittle, and not very soluble in acids. Its specific gravity was 6.700; it was not so fusible as copper; and when combined with iron rendered it *cold short*. Both of them concluded that this substance was a new metal: Bergman gave it the name of *siderum*, and Meyer of *hydrosiderum*. But Klaproth soon after recollecting that the salt composed of phosphoric acid and iron bore a great resemblance to the white powder obtained from cold short iron, suspected the presence of phosphoric acid in this new metal. To decide the point, he combined phosphoric acid and iron, and obtained, by heating it in a crucible along with charcoal powder [*], a substance exactly resembling the new metal [†]. Meyer, when Klaproth communicated to him this discovery, informed him that he had already satisfied himself, by a more accurate examination, that siderum contained phosphoric acid [‡]. Soon after this, Scheele actually decomposed the white powder obtained from cold short iron, and thereby demonstrated, that it is composed of phosphoric acid and iron [§]. The siderum of Bergman, however, is composed of phosphorus and iron, or it is phosphuret of iron; the phosphoric acid being deprived of its oxygen during the *reduction* [||].

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[*] This process in chemistry is called *reduction*.

[†] Crell's *Annals*, 1784, i. 390.

[‡] Ibid. 195.

[§] Crell, i. 112. Engl. Trans.

[||] Rinman has shewn that the brittleness and bad qualities of cold short iron may be removed by heating it strongly with limestone, and with this the experiments of Levavasseur correspond. See *Ann. de Chim.* xlii. 183.

Carburet.

5. Carburet of iron is found native, and has been long known under the names of *plumbago* and *black lead*. It is of a dark iron grey or blue colour, and has something of a metallic lustre. It has a greasy feel, and blackens the fingers, or any other substance to which it is applied. It is found in many parts of the world, especially in Britain, where it is manufactured into pencils. It is not affected by the most violent heat as long as air is excluded, nor is it in the least altered by simple exposure to the air or to water. A moderate heat has no effect upon it; but when heated very strongly in an open vessel, it burns all away slowly except about $\frac{1}{10}$ of a residuum, which is oxide of iron *. Its nature was first investigated by Scheele; who proved, by a very ingenious analysis, published in the Stockholm Transactions for 1779, that it can be converted by combustion almost wholly into carbonic acid gas, and that the small residuum is iron †. He concluded from his analysis, that it is composed of carbonic acid and phlogiston: but the experiments of Pelletier, and, above all, of Vandermonde, Monge and Berthollet, have demonstrated, that it is a compound of about nine parts of carbon and one of iron ‡. The difficult combustion of plumbago is not merely owing to the presence of the iron, but to the state of the carbon, which appears to be nearly pure, or at least to be combined with only a very small portion of oxygen.

Varieties of iron.

6. There are a great many varieties of iron, which artists distinguish by particular names; but all of them may be reduced under one or other of the three fol-

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* Gahn.

† Scheele, ii. 20. French Transl.

‡ *Mem. Par.* 1786.

lowing classes—*Cast Iron*, *Wrought* or *Soft Iron*, and *Steel*.

Cast iron.

CAST IRON, or PIG IRON, is the name of the metal when first extracted from its ores. The ores from which iron is usually obtained are composed of oxide of iron and clay. The object of the manufacturer is to reduce the oxide to the metallic state, and to separate all the clay with which it is combined. These two objects are accomplished at once, by mixing the ore reduced to small pieces with a certain portion of limestone and of charcoal, and subjecting the whole to a very violent heat in furnaces constructed for the purpose. The charcoal absorbs the oxygen of the oxide, flies off in the state of carbonic acid gas, and leaves the iron in the metallic state; the lime combines with the clay, and both together run into fusion, and form a kind of fluid glass; the iron is also melted by the violence of the heat, and being heavier than the glass, falls down, and is collected at the bottom of the furnace. Thus the contents of the furnace are separated into two portions; the glass swims at the surface, and the iron rests at the bottom. A hole at the lower part of the furnace is now opened, and the iron allowed to flow out into moulds prepared for its reception.

The cast iron thus obtained is distinguished by the following properties: It is scarcely malleable at any temperature. It is generally so hard as to resist the file. It can neither be hardened nor softened by ignition and cooling. It is exceedingly brittle. It melts at 130° Wedgewood. It is more sonorous than steel *.

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* Dr Pearson on *Wootz*, *Phil. Trans.*

For the most part it is of a dark grey or blackish colour; but sometimes it is whitish, and then it contains a quantity of phosphuret of iron, which considerably impairs its qualities. A great number of utensils are formed of iron in this state.

Soft iron.

To convert it into WROUGHT IRON, it is put into a furnace, and kept melted, by means of the flame of the combustibles, which is made to play upon its surface. While melted, it is constantly stirred by a workman, that every part of it may be exposed to the air. In about an hour the hottest part of the mass begins to heave and swell, and to emit a lambent blue flame. This continues nearly an hour; and by that time the conversion is completed. The heaving is evidently produced by the emission of an elastic fluid *. As the process advances, the iron gradually acquires more consistency; and at last, notwithstanding the continuance of the heat, it congeals altogether. It is then taken while hot, and hammered violently, by means of a heavy hammer driven by machinery. This not only makes the particles of iron approach nearer each other, but drives away several impurities which would otherwise continue attached to the iron.

In this state it is the substance described in this Section under the name of IRON. As it has never yet been decomposed, it is considered at present when pure as a simple body; but it has seldom or never been found without some small mixture of foreign substances. These substances are either some of the other metals, or oxygen, carbon, or phosphorus.

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* Beddoes, *Phil. Trans.* 1791.

Steel.

When small pieces of iron are stratified in a close crucible, with a sufficient quantity of charcoal powder, and kept in a strong red heat for eight or ten hours, they are converted into STEEL[*], which is distinguished from iron by the following properties.

It is so hard as to be unmalleable while cold, or at least it acquires this property by being immersed while ignited into a cold liquid: for this immersion, though it has no effect upon *iron*, adds greatly to the hardness of *steel*.

It is brittle, resists the file, cuts glass, affords sparks with flint, and retains the magnetic virtue for any length of time. It loses this hardness by being ignited and cooled very slowly. It melts at above 130° Wedgewood. It is malleable when red hot, but scarcely so when raised to a white heat. It may be hammered out into much thinner plates than iron. It is more sonorous; and its specific gravity, when hammered, is greater than that of iron.

By being repeatedly ignited in an open vessel, and hammered, it becomes *wrought iron*[†].

Nature of these varieties.

7. These different kinds of iron have been long known, and the converting of them into each other has been practised in very remote ages. Many attempts have been made to explain the manner in which this conversion is accomplished. According to Pliny, steel owes its peculiar properties chiefly to the water into which it is plunged in order to be cooled[‡]. Beccher supposed that fire was the only agent; that it entered

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[*] This process is called *cementation*.

[†] Dr Pearson on *Wootz*, *Phil. Trans.*

[‡] Pliny, lib. xxxiv. 14.

into the iron, and converted it into steel. Reaumur was the first who attended accurately to the process; and his numerous experiments have certainly contributed to elucidate the subject. He supposed that iron is converted into steel by combining with saline and oily or sulphureous particles, and that these are introduced by the fire. But it was the analysis of Bergman, published in 1781, that first paved the way to the explanation of the nature of these different species of iron *.

By dissolving in diluted sulphuric acid 100 parts of cast iron, he obtained, at an average, 42 ounce measures of hydrogen gas; from 100 parts of steel he obtained 48 ounce measures; and from 100 parts of wrought iron, 50 ounce measures. From 100 parts of cast iron, he obtained, at an average, 2.2 of plumbago, or $\frac{1}{45}$; from 100 parts of steel, 0.5, or $\frac{1}{200}$; and from 100 parts of wrought iron, 0.12, or $\frac{1}{800}$. From this analysis he concluded, that cast iron contains the least phlogiston, steel more, and wrought iron most of all: for the hydrogen gas was at that time considered as an indication of the phlogiston contained in the metal He concluded, too, that cast iron and steel differ from pure iron in containing plumbago. Mr Grignon, in his notes on this analysis, endeavoured to prove, that plumbago is not essentially a part of cast iron and steel, but that it was merely accidentally present. But Bergman, after considering his objections, wrote to Morveau on the 18th November 1783. "I will acknowledge my mistake whenever Mr Grignon sends me a single bit of cast iron or steel, which does not contain plum-

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* *Opusc.* iii. 1.

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bago; and I beg of you, my dear friend, to endeavour to discover some such, and to send them to me; for if I am wrong, I wish to be undeceived as soon as possible*." This was almost the last action of the illustrious Bergman. He died a few months after at the age of 49, leaving behind him a most brilliant reputation, which no man ever more deservedly acquired. His industry, his indefatigable, his astonishing industry, would alone have contributed much to establish his name; his extensive knowledge would alone have attracted the attention of philosophers; his ingenuity, penetration, and accurate judgment, would alone have secured the applause; and his candour and love of truth procured him the confidence and the esteem of the world.—But all these qualities were united in Bergman, and conspired to form one of the noblest characters that ever adorned human nature.

Explained.

The experiments of Bergman were repeated, varied, and extended, by Vandermonde, Monge, and Berthollet, who published an admirable dissertation on the subject in the Memoirs of the French Academy for 1786. These philosophers, by an ingenious application of the theoretical discoveries of Mr Lavoisier and his associates, were enabled to explain the nature of these three substances in a satisfactory manner. By their experiments, together with the subsequent ones of Clouet, Vauquelin, and Morveau, the following facts have been established.

Wrought iron is a simple substance, and if perfectly pure would contain nothing but *iron*.

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* Morveau, *Encyc. Method. Chim.* i. 448.

Steel is iron combined with a small portion of carbon, and has been for that reason called *carbureted iron.* The proportion of carbon has not been ascertained with much precision. From the analysis of Vauquelin, it amounts, at an average, to $\frac{1}{140}$ part*. Mr Clouet seems to affirm that it amounts to $\frac{1}{32}$ part; but he has not published the experiments which led him to a proportion, which so far exceeds what has been obtained by other chemists †.

That steel is composed of iron combined with pure carbon, and not with charcoal, has been demonstrated by Morveau, who formed steel by combining together directly iron and diamond. At the suggestion of Clouet, he inclosed a diamond in a small crucible of pure iron, and exposed it completely covered up in a common crucible to a sufficient heat. The diamond disappeared, and the iron was converted into steel. The diamond weighed 907 parts, the iron 57800; and the steel obtained 56384; so that 2313 parts of the iron had been lost in the operation ‡. From this experiment it follows, that steel contains about $\frac{1}{60}$ of its weight of carbon. This experiment was objected to by Mr Mushet,

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* *Ann. de Chim.* xxii. 1:

† Mr Clouet's words are as follows: "Le charbon s'unit au fer en différentes proportions; et à mesure que ces proportions varient, les produits varient aussi. Un trente-deuxième de charbon suffit pour rendre le fer acier; cette dose varie cependant dans les expériences, à cause de l'inégale intensité du ſeu et de la porosité des creusets: en augmentant la dose de charbon, la qualité de l'acier augmente aussi; mais il devient toujours de plus en plus difficile à forger, et plus facile à ramollir au feu." *Jour. de Min.* An. vii. 3.

‡ *Ann. de Chim.* xxxi. 328.

but the objections were fully refuted by Sir George M'Kenzie [*].

Rinman, long ago, pointed out a method by which steel may be distinguished from iron. When a little diluted nitric acid is dropt upon a plate of steel, allowed to remain a few minutes, and then washed off, it leaves behind it a black spot; whereas the spot formed by nitric acid on iron is whitish green. We can easily see the reason of the black spot: it is owing to the carbon of the iron which is converted into charcoal by the acid. This experiment shows us, that carbon is much more readily oxidated when combined with iron than when crystallized in the diamond.

Cast iron, is iron combined with a still greater proportion of carbon than is necessary for forming steel. The quantity has not yet been ascertained with precision: Mr Clouet makes it amount to $\frac{1}{8}$ of the iron. The blackness of the colour, and the fusibility of cast iron, are proportional to the quantity of carbon which it contains. Cast iron is almost always contaminated with foreign ingredients: These are chiefly oxide of iron, phosphuret of iron, and silica [†].

Manufacture of

8. It is easy to see why iron is obtained from its ore in the state of cast iron. The quantity of charcoal, along with which the ore is fused, is so great, that the iron has an opportunity of saturating itself with it.

Soft iron,

The conversion of cast iron into wrought iron is effected by burning away the charcoal, and depriving the iron wholly of oxygen: this is accomplished by heat-

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[*] Nicholson's *Journal*, iv. 103.

[†] A substance which shall be described in the next Book.

ing it violently while exposed to the air *. Mr Clouet has found, that when cast iron is mixed with $\frac{1}{4}$ of its weight of black oxide of iron, and heated violently, it is equally converted into pure iron. The oxygen of the oxide, and the carbon of the cast iron, combine, and leave the iron in a state of purity †.

The conversion of iron into steel is effected by combining it with carbon. This combination is performed in the large way by three different processes, and the products are distinguished by the names of *natural steel*, *steel of cementation*, and *cast steel*.

Natural steel,

Natural steel is obtained from the ore by converting it first into cast iron, and then exposing the cast iron to a violent heat in a furnace while its surface is covered with a mass of melted scoriæ five or six inches deep. Part of the carbon combines with the oxygen which cast iron always contains, and flies off in the state of carbonic acid gas. The remainder combines with the pure iron, and constitutes it steel ‡. This steel is inferior to the other species; its quality is not the same throughout, it is softer, and not so apt to break; and as the processes by which it is obtained is less expensive, it is sold at a lower price than the other species.

Steel of cementation,

Steel of cementation is made by stratifying bars of pure iron and charcoal powder alternately in large earthen troughs or crucibles, the mouths of which are

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* A detailed account of the processes used at Sheffield for converting cast iron into pure iron, has been published by Mr Collier in the 5th volume of the *Manchester Memoirs*, p. 111.

† *Jour. de Min.* An. vii. p. 8.

‡ A detailed account of this process, as performed in different iron works, may be seen in the *Jour. de Min.* N° iv. p. 3.

carefully closed up with clay. These troughs are put into a furnace, and kept sufficiently hot till the bars of iron are converted into steel, which usually requires eight or ten days *. This process was invented, or at least first practised to any extent, in Britain. The bars of steel thus formed are known in this country by the name of *blistered steel*, because their surface is covered here and there with a kind of blister of the metal, as if an elastic fluid had been confined in different parts of it. When drawn out into smaller bars by the hammer, it receives the name of *tilted steel*, from the hammer employed. When broken to pieces, and welded repeatedly in a furnace, and then drawn out into bars, it is called *German* or *shear steel*†. Steel of cementation has a fine grain, is equable, harder, and more elastic than *natural steel*.

Cast steel. Cast steel is the most valuable of all, as its texture is most compact, and it admits of the finest polish. It is used for razors, surgeons instruments, and other similar purposes. It is more fusible than common steel, and for that reason cannot be welded with iron: it melts before it can be heated high enough. The method of making it was discovered about 1750 by Mr Huntsman of Sheffield, who still continues to manufacture it. The process was for some time kept secret; but it is now well known in this country, and other manufacturers succeed in it equally well with the original discoverer. It consists in fusing blistered steel in a close crucible, mixed with a certain proportion of pounded glass and

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* The process is described at large by Mr Collier in the *Manchester Memoirs* v. 117.

† Collier, *Manchester Memoirs*, v. 117.

charcoal powder. It may be formed also, according to the experiments of Clouet, by melting together 30 parts of iron, one part of charcoal, and one part of pounded glass; or, by surrounding iron in a crucible with a mixture of equal parts of chalk and clay, and heating the crucible gradually to a white heat, and keeping it a sufficient time in that state *. The carbon, according to Clouet, is obtained by the decomposition of the carbonic acid, which exists abundantly in the chalk: one part of the iron combining with the oxide of this acid, while the other part combines with the iron †. But the subsequent experiments of Mr Mushet have rendered it very probable that this theory is erroneous, and that the steel obtained by Clouet was owing to some other unobserved circumstance: for when he repeated it with with all possible precision, he obtained only iron, which had been melted, and thereby altered in its texture and appearance, but not converted into steel ‡. From the experiments of Clouet it does not appear that the presence of glass is necessary to constitute cast steel; the only essential ingredients seem to be iron and carbon: but the quantity of carbon is greater than in common steel, and this seems to constitute the difference between these two substances.

9. From the preceding detail, it is obvious that iron and carbon are capable of combining together in a variety of different proportions. When the carbon exceeds, the compound is carburet of iron or plumbago. When the iron exceeds, the compound is steel or cast

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* *Jour. de Min.* An. vii. 3.

† Guyton and Darcet, *Ibid.* An. vi. 703.

‡ *Phil. Mag.* xii. 27.

iron in various states, according to the proportion. All these compounds may be considered as *subcarburets of iron.* The most complete detail of experiments on these various compounds which have appeared in this country are those of Mr Mushet, published in the Philosophical Magazine. This ingenious practical chemist has observed, that the hardness of iron increases with the proportion of charcoal with which it combines, till the carbon amounts to about $\frac{1}{60}$ of the whole mass. The hardness is then a maximum; the metal acquires the colour of silver, loses its granulated appearance, and assumes a crystallized form. If more carbon be added to the compound, the hardness diminishes in proportion to its quantity *.

Subcarburets of iron.

The following TABLE, by the same ingenious chemist, exhibits the proportion of charcoal which disappeared during the conversion of iron to the different varieties of subcarburet known in commerce †.

Charcoal absorbed.	Result.
$\frac{1}{120}$	Soft cast steel
$\frac{1}{100}$	Common cast steel
$\frac{1}{90}$	The same, but harder
$\frac{1}{50}$	The same, too hard for drawing
$\frac{1}{25}$	White cast iron
$\frac{1}{20}$	Mottled cast iron
$\frac{1}{15}$	Black cast iron

IV. Iron does not combine with azote. Muriatic acid gas oxidizes it, and combines with the oxide, unless the gas be freed from water.

Alloys with

V. Iron combines with most metals.

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* *Phil. Mag.* xiii. 148.

† *Ibid.* p. 142.

Gold,

1. The alloy of gold and iron is very hard, and might, according to Dr Lewis who examined it, be employed with advantage in forming cutting instruments. When these metals are combined in equal proportions, the colour of the alloy is grey: Four parts of iron and one of gold give an alloy almost of the colour of silver. Its specific gravity is less than the mean *. Gold has been proposed as an excellent solder for steel.

Platinum,

2. Platinum is usually found alloyed with iron. Dr Lewis did not succeed in his attempts to unite these metals by fusion, but he melted together cast iron and platinum. The alloy was excessively hard, and possessed ductility.

Silver,

3. From the experiments of Gellert † we learn, that iron and silver unite very readily: But Morveau ‡ has shown, that when this alloy is kept in fusion, the metals separate from each other according to their specific gravity, forming two buttons, exceedingly distinct. Neither of these, however, is in a state of purity. The silver retains a little iron, which makes it obedient to the magnet. Coulomb has shown, that the proportion of iron which remained in the silver amounts to $\frac{1}{320}$th part. The iron, on the other hand, retains about $\frac{1}{80}$th of its weight of silver; which gives it an excessive hardness and compactness of structure of which pure iron is destitute §.

Mercury,

4. Iron is not acted on by mercury: accordingly this last metal is usually kept in vessels of iron. Mr Arthur Aiken, however, has lately shown that these two

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* Gellert.

† *Metallurgic Chem.*

‡ *Jour. de Phys.* 1778.

§ *Ann. de Chim.* xliii. 47.

metals may be combined together. To form an amalgam of iron, he triturates together iron filings and the amalgam of the metal called zinc, and adds to the mixture a solution of iron in muriatic acid. By kneading this mixture and heating it, the iron and mercury which combine together gradually assume the metallic lustre [*].

Copper.

5. Iron may be united to copper by fusion, but not without considerable difficulty. The alloy has been applied to no use. It is of a grey colour, has but little ductility, and is much less fusible than copper. Mr Levavasseur has published some observations which render it probable that the variety of iron called *hot-short* iron, because it is brittle when red hot, sometimes owes its peculiarities to the presence of copper. This variety possesses a greater degree of tenacity than common iron, and therefore answers better for some purposes. It may be hammered when white hot. As soon as it cools, so far as to assume a brown colour, the forging must be stopt till it becomes of an obscure cherry red, and then it may be continued till the iron is quite cold [†].

Affinities.

VI. The affinities of iron, and its oxides, are arranged by Bergman as in the following Table:

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[*] *Phil. Mag.* xiii. 416.

[†] *Ann. de Chim.* xlii. 183.

Iron.	Oxide of Iron.
Nickel,	Oxalic acid,
Cobalt,	Tartaric,
Manganese,	Camphoric *,
Arsenic,	Sulphuric,
Copper,	Saclactic,
Gold,	Muriatic,
Silver,	Nitric,
Tin,	Phosphoric,
Antimony,	Arsenic,
Platinum,	Fluoric,
Bismuth,	Succinic,
Lead,	Citric,
Mercury.	Lactic,
	Acetic,
	Boracic,
	Prussic,
	Carbonic.

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* Bouillon La Grange.

SECT. VII.

OF TIN.

I. TIN was known to the ancients in the most remote ages. The Phœnicians procured it from Spain* and from Britain, with which nations they carried on a very lucrative commerce. At how early a period they imported this metal we may easily conceive, if we recollect that it was in common use in the time of Moses†.

Properties.

1. This metal has a fine white colour like silver; and when fresh, its brilliancy is very great. It has a slightly disagreeable taste, and emits a peculiar smell when rubbed.

2. Its hardness is 6‡. Its specific gravity is 7.291; after hammering, 7.299§.

3. It is very malleable: tin leaf, or *tinfoil* as it is called, is about $\frac{1}{1000}$ part of an inch thick, and it might be beat out into leaves as thin again if such were wanted for the purposes of art. Its ductility and tenacity are much inferior to that of any of the metals hitherto described. A tin wire $\frac{1}{12.0}$ inch in diameter is capable of supporting a weight of 31 pounds only without breaking ‖. Tin is very flexible, and produces a remarkable crackling noise when bended.

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* Pliny, lib. iv. cap. 34. and lib. xxxiv. cap. 47.

† Numbers xxxi. 22.

‡ Kirwan's *Miner.* ii. 195.

§ Brisson.

‖ Muschenbroeck

4. When heated to the temperature of 442°* it melts; but a very violent heat is necessary to cause it to evaporate. When cooled slowly, it may be obtained crystallized in the form of a rhomboidal prism†.

Oxides.

II. When exposed to the air, it very soon loses its lustre, and assumes a greyish white colour; but undergoes no farther change. Neither is it sensibly altered by being kept under cold water; but when the steam of water is made to pass over red hot tin, it is decomposed, the tin is oxidated, and hydrogen gas is evolved ‡.

When tin is melted in an open vessel, its surface becomes very soon covered with a grey powder, which is an oxide of the metal. If the heat be continued, the colour of the powder gradually changes, and at last it becomes yellow. In this state it is known by the name of *putty*, and employed in polishing glass and other hard bodies. When tin is heated very violently in an open vessel, it takes fire, and is converted into a fine white oxide, which may be obtained in crystals.

Mr Proust has demonstrated, that tin is capable of combining with two different proportions of oxygen, and of forming two oxides, usually distinguished on account of their colour by the names of the *yellow* and the *white oxide* §.

Protoxide.

1. The protoxide may be obtained by exposing tin to a strong heat under a muffle, constantly stirring it with a rod. It may be procured also by dissolving tin

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* Crichton, *Phil. Mag.* xv. 147.

† Pajot, *Jour. de Phys.* xxxviii. 52.

‡ Bouillon La Grange, *Ann. de Chim.* xxxv. 28.

§ *Ibid.* xxviii. 213.

in diluted nitric acid without the assistance of heat, and then precipitating the oxide by pure potass; but in that case it retains a little acid, and has a white colour. It is composed of about 20 parts of oxygen and 80 of tin.

Peroxide.

2. The peroxide may be obtained by heating tin in concentrated nitric acid. A violent effervescence ensues, and the whole of the tin is converted into a white powder, which is deposited at the bottom of the vessel. It is composed of about 28 parts of oxygen and 72 of tin.

Union with combustibles.

III. Tin combines with sulphur and phosphorus; but it has never been combined with carbon nor hydrogen.

Sulphuret.

1. Sulphuret of tin may be formed by throwing bits of sulphur upon the metal melted in a crucible, or by fusing the two ingredients together. It is brittle, heavier than tin, and not so fusible. It is of a bluish colour and lamellated structure, and is capable of crystallizing. According to Bergman, it is composed of 80 parts of tin and 20 of sulphur; according to Pelletier, of 85 parts of tin and 15 of sulphur *.

Sulphureted oxide.

2. When equal parts of white oxide of tin and sulphur are mixed together and heated gradually in a retort, some sulphur and sulphurous acid are disengaged, and there remains a substance composed of 40 parts of sulphur and 60 of white oxide of tin, formerly called *aurum musivum, musicum* or *mosaicum*, and now *sulphureted oxide of tin*. It consists of beautiful gold coloured flakes, exceedingly light, which adhere to the skin.

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* *Ann. de Chim.* xiii. 287.

The process for making this substance was formerly very complicated. Pelletier first demonstrated its real composition, and was hence enabled to make many important improvements in the manner of manufacturing it *.

Phosphuret.

3. Phospuret of tin may be formed by melting in a crucible equal parts of filings of tin and phosphoric glass. Tin has a greater affinity for oxygen than phosphorus has. Part of the metal therefore combines with the oxygen of the glass during the fusion, and flies off in the state of an oxide, and the rest of the tin combines with the phosphorus. The phosphuret of tin may be cut with a knife; it extends under the hammer, but separates in laminæ. When newly cut, it has the colour of silver; its filings resemble those of lead. When these filings are thrown on burning coals, the phosphorus takes fire. This phosphuret may likewise be formed by dropping phosphorus gradually into melted tin. According to Pelletier, to whose experiments we are indebted for the knowledge of all the phosphurets, it is composed of about 85 parts of tin and 15 of phosphorus †. Margraf also formed this phosphuret, but he was ignorant of its composition.

IV. Tin does not combine with azote nor muriatic acid; though the last substance converts it into an oxide.

Alloys with

V. Tin is capable of combining with most of the metals, and some of its alloys are much employed. The greater number of them are brittle. The older metallurgists considered it as a property of tin to render

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* See his Memoir, *Ann. de Chim.* xiii. 280.

† *Ibid.* 116.

other metals brittle. Hence they called it *diabolus metallorum* *.

Gold,

1. It mixes readily with gold by fusion; but the proportions in which these metals combine chemically are still unknown. When one part of tin and twelve of gold are melted together, the alloy is brittle, hard, and bad coloured. Twenty-four parts of gold and one of tin produce a pale coloured alloy, harder than gold, but possessed of considerable ductility. Gold alloyed with no more than $\frac{1}{11}$ of tin is scarcely altered in its properties, according to Mr Alchorne †; but Mr Tillet, who more lately examined this alloy, found, that whenever it was heated it broke into a number of pieces. It is very difficult to separate these metals from each other. The best method is to fuse the alloy with sulphuret of antimony.

Platinum,

2. The alloy of platinum and tin is very fusible and brittle, at least when these metals are mixed in equal proportions ‡. Twelve parts of tin and one of platinum form an alloy possessed of considerable ductility, which becomes yellow when exposed to the air.

Silver,

3. The alloy of silver and tin is very brittle, hard, and durable. The two metals can scarcely be separated again by the usual processes. This alloy has been applied to no use.

Mercury,

4. Mercury dissolves tin very readily cold; and these metals may be combined in any proportion by pouring mercury into melted tin. The amalgam of tin, when composed of three parts of mercury and one of tin, cry-

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* See Etmuller's *Chemistry*, p. 332.

† Alchorne, *Phil. Trans.*

‡ Dr Lewis.

stallizes in the form of cubes, according to Daubenton; but, according to Sage, in grey brilliant square plates, thin towards the edges, and attached to each other so that the cavities between them are polygonal. It is used to silver the backs of glass mirrors.

Copper,

5. Tin unites very readily with copper, and forms an alloy exceedingly useful for a great variety of purposes. Of this alloy cannons are made: bell metal, bronze, and the mirrors of telescopes are formed of different proportions of the same metals. The addition of tin diminishes the ductility of copper, and increases its hardness, tenacity, fusibility, and sonorousness. The specific gravity of the alloy is greater than the mean density of the two metals. It appears from the experiments of Mr Briche, that this augmentation of density increases with the tin; and that the specific gravity, when the alloy contains 100 parts of copper and 16 of tin, is a maximum: it is 8.87. The specific gravity of equal parts of tin and copper is 8.79, but it ought only to be 8; consequently the density is increased 0.79 *. In order to mix the two metals exactly, they ought to be kept a long time in fusion, and constantly stirred, otherwise the greater part of the copper will sink to the bottom, and the greater part of the tin rise to the surface; and there will be formed two different alloys, one composed of a great proportion of copper combined with a small quantity of tin, the other of a great proportion of tin alloyed with a small quantity of copper.

Bronze,

Bronze and the metal of cannons are composed of

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* *Jour. de Min.* An. v. 881.

from 6 to 12 parts of tin combined with 100 parts of copper. This alloy is brittle, yellow, heavier than copper, and has much more tenacity; it is much more fusible, and less liable to be altered by exposure to the air. It was this alloy which the ancients used for sharp-edged instruments before the method of working iron was brought to perfection. The χαλκος of the Greeks, and perhaps the *æs* of the Romans, was nothing else. Even their copper coins contain a mixture of tin*.

Bell metal.

Bell metal is usually composed of three parts of copper and one part of tin. Its colour is greyish white; it is very hard, sonorous, and elastic. The greater part of the tin may be separated by melting the alloy, and then pouring a little water on it. The tin decomposes the water, is oxidated, and thrown upon the surface.

Mirrors.

The mirrors of telescopes are formed by melting together three parts of tin and one part of copper. This alloy is very hard, of the colour of steel, and admits of a fine polish. But besides this, there are many other compounds often used for the same purpose.

Tinned copper.

Vessels of copper, especially when used as kitchen utensils, are usually covered with a thin coat of tin to prevent the copper from oxidating, and to preserve the food which is prepared in them from being mixed with any of that poisonous metal. These vessels are then said to be *tinned*. Their interior surface is scraped very clean with an iron instrument, and rubbed over with sal ammoniac. The vessel is then heated, and a little pitch thrown into it, and allowed to spread on the surface. Then a bit of tin is applied all over the hot

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* See Dize's Analysis, *Jour. de Phys.* 1790.

copper, which instantly assumes a silvery whiteness. The intention of the previous steps of the process is to have the surface of the copper perfectly pure and metallic; for tin will not combine with the oxide of copper. The coat of tin thus applied is exceedingly thin. Bayen ascertained, that a pan nine inches in diameter, and three inches three lines in depth, when tinned, only acquired an additional weight of 21 grains. Nor is there any method of making the coat thicker. More tin indeed may be applied; but a moderate heat melts it, and causes it to run off.

Iron.

6. Tin does not combine readily with iron. An alloy, however, may be formed, by fusing them in a close crucible, completely covered from the external air. We are indebted to Bergman for the most precise experiments on this alloy. When the two metals were fused together, he always obtained two distinct alloys: the first, composed of 21 parts of tin and one part of iron; the second, of two parts of iron and one part of tin. The first was very malleable, harder than tin, and not so brilliant; the second but moderately malleable, and too hard to yield to the knife[*].

Tinplate.

The formation of *tinplate* is a sufficient proof of the affinity between these two metals. This very useful alloy, known in Scotland by the name of *white iron*, is formed by dipping into melted tin thin plates of iron, thoroughly cleaned by rubbing them with sand, and then steeping them 24 hours in water acidulated by bran or sulphuric acid. The tin not only covers the surface of the iron, but penetrates it completely, and gives the whole a white colour.

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[*] Bergman, iii. 471.

Book I.
Division I.

Affinities.

VI. The affinities of tin, and its oxides, are, according to Bergman, as follows:

TIN.	OXIDE OF TIN.
Zinc,	Tartaric acid,
Mercury,	Muriatic,
Copper,	Sulphuric,
Antimony,	Oxalic,
Gold,	Arsenic,
Silver,	Phosphoric,
Lead,	Nitric,
Iron,	Succinic,
Manganese,	Fluoric,
Nickel,	Saclactic,
Arsenic,	Citric,
Platinum,	Lactic,
Bismuth,	Acetic,
Cobalt,	Boracic,
Sulphur,	Prussic.

SECT. VIII.

OF LEAD.

I. LEAD appears to have been very early known. It is mentioned several times by Moses. The ancients seem to have considered it as nearly related to tin.

Properties.

1. Lead is of a bluish white colour; and when newly melted is very bright, but it soon becomes tarnished by exposure to the air. It has scarcely any taste, but emits on friction a peculiar smell. It stains paper or the fingers of a bluish colour. When taken internally it acts as a poison.

2. Its hardness is $5\frac{1}{2}$; its specific gravity is 11.3523*. Its specific gravity is not increased by hammering, neither does it become harder, as is the case with other metals: a proof that the hardness which metals assume under the hammer is in consequence of an increase of density.

3. It is very malleable, and may be reduced to very thin plates by the hammer; it may be also drawn out into wire, but its ductility is not great. Its tenacity is such, that a lead wire $\frac{1}{12.8}$ inch diameter is capable of supporting only 18.4 pounds without breaking.

4. It melts, according to Sir Isaac Newton, when heated to the temperature of 540° Fahrenheit; but Morveau makes its fusing point as high as 594°. When a very strong heat is applied, the metal boils and

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* Brisson.

evaporates. If it be cooled slowly, it crystallizes. The Abbé Mongez obtained it in quadrangular pyramids, lying on one of their sides. Each pyramid was composed as it were of three layers. Pajot obtained it in the form of a polyhedron with 32 sides, formed by the concourse of six quadrangular pyramids *.

Oxides.

Action of air.

II. When exposed to the air, it soon loses its lustre, and acquires first a dirty grey colour, and at last its surface becomes almost white. This is owing to its gradual combination with oxygen, and conversion into an oxide: but this conversion is exceedingly slow; the external crust of oxide, which forms first, preserving the rest of the metal for a long time from the action of the air.

Action of water.

Water has no direct action upon lead; but it facilitates the action of the external air. For, when lead is exposed to the air, and kept constantly wet, it is oxidated much more rapidly than it otherwise would be. Hence the reason of the white crust which appears upon the sides of leaden vessels containing water, just at the place where the upper surface of the water usually terminates.

Protoxide.

No less than four different combinations of lead with oxygen are at present known, though some of them have not been examined with much attention.

1. The protoxide, or first oxide of lead, may be obtained by dissolving lead in nitric acid, and boiling the crystals which that solution yields by concentration along with pieces of metallic lead. The consequence is the formation of scaly crystals of a yellow colour, brilliant and very soluble in water. These crystals are

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* *Journ. de Phys.* xxxviii. 53.

composed of the protoxide of lead combined with nitric acid. They were discovered by Mr Proust[*]. The protoxide may be precipitated by means of potass. Its properties have not hitherto been examined. It contains but a small proportion of oxygen.

Deutoxide.

2. The deutoxide of lead may be formed by dissolving the metal in nitric acid, and pouring potass into the solution. A yellow coloured powder is obtained, which is the deutoxide of lead. This oxide, according to the experiments of Proust, is composed of 91 parts of lead, and 9 of oxygen[†]. When lead is kept melted in an open vessel, its surface is soon covered with a grey coloured pellicle. When this pellicle is removed, another succeeds it; and by continuing the heat, the whole of the lead may soon be converted into this substance. If these pellicles be heated and agitated for a short time in an open vessel, they assume the form of a greenish grey powder. Mr Proust has shewn that this powder is a mixture of deutoxide, and a portion of lead in the metallic state. It owes its green colour to the blue and yellow powders which are mixed in it. If we continue to expose this powder to heat for some time longer in an open vessel, it absorbs more oxygen, assumes a yellow colour, and is then known in commerce by the name of *massicot*. The reason of this change is obvious. The metallic portion of the powder gradually absorbs oxygen, and the whole of course is converted into deutoxide.

Dross of lead.

White lead.

When thin plates of lead are exposed to the vapour of warm vinegar, they are gradually corroded, and con-

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[*] *Jour. de Phys.* lvi. 206.

[†] *Ibid.*

verted into a heavy white powder, used as a paint, and called *white lead.* This powder used formerly to be considered as a peculiar oxide of lead; but it is now known that it is a compound of the deutoxide and carbonic acid.

Red lead.

3. If massicot ground to a fine powder be put into a furnace, and constantly stirred while the flame of the burning coals plays against its surface, it is in about 48 hours converted into a beautiful red powder known by the name of *minium* or *red lead.* This powder, which is likewise used as a paint, and for various other purposes, is the *tritoxide* or *red oxide of lead.*

Peroxide.

4. If nitric acid, of the specific gravity 1.260, be poured upon the red-coloured oxide of lead, 185 parts of the oxide are dissolved; but 15 parts remain in the state of a black or rather deep brown powder *. This is the *peroxide* or *brown oxide of lead*, first discovered by Scheele. The best method of preparing it is the following, which was pointed out by Proust, and afterwards still farther improved by Vauquelin: Put a quantity of red oxide of lead into a vessel partly filled with water, and make oxy-muriatic acid gas pass into it. The oxide becomes deeper and deeper coloured, and is at last dissolved. Pour potass into the solution, and the brown oxide of lead precipitates. By this process 68 parts of brown oxide may be obtained for every 100 of red oxide employed †. This oxide is composed of about 79 parts of lead and 21 of oxygen. It is of a brilliant flea brown colour. When heated it emits oxygen gas, becomes yellow, and melts into a kind of glass. When

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* Scheele, i. 113. and Proust, *Ann. de Chim.* xxiii. 98.

† Fourcroy, iv. 91.

rubbed along with sulphur in a mortar, it sets the sulphur on fire, and causes it to burn with a brilliant flame. When heated on burning coals the lead is reduced *.

Cupellation.

All the oxides of lead are very easily converted into glass; and in that state they oxidize and combine with almost all the other metals except gold, platinum, and silver. This property renders lead exceedingly useful in separating gold and silver from the baser metals with which they happen to be contaminated. The gold or silver to be purified is melted along with lead, and kept for some time in that state in a flat cup, called a *cupel*, made of burnt bones, or the ashes of wood. The lead is gradually vitrified and sinks into the cupel, carrying along with it all the metals which were mixed with the silver and gold, and leaving these metals on the cupel in a state of purity. This process is called *cupellation*. The lead employed is afterwards extracted from the cupels, and is known in commerce by the name of *litharge*. It is a half vitrified substance, of a high red colour, and composed of scales. It is merely an oxide of lead more or less contaminated with the oxides of other metals. But the best litharge is made by oxidizing lead directly, and then increasing the heat till the oxide is fused. The more violent the fusing heat the whiter is the litharge †.

Litharge.

Union with combustibles.

III. Lead has not yet been combined with carbon, nor hydrogen; but it combines readily with sulphur and phosphorus.

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* Vauquelin, *Fourcroy*, vi. 92.

† Some improvements in the method of separating silver from lead by cupellation, may be seen in a dissertation by Duhamel published in the 3d Vol. of the *Memoires de l'Institute*, p. 306.

Sulphuret.

1. Sulphuret of lead may be formed either by stratifying its two component parts and melting them in a crucible, or by dropping sulphur at intervals on melted lead. The sulphuret of lead is brittle, brilliant, of a deep blue grey colour, and much less fusible than lead. These two substances are often found naturally combined; the compound is then called *galena*, and is usually crystallized in cubes. Sulphuret of lead is composed, according to the experiments of Wenzel, of 86.8 parts of lead and 13.2 of sulphur *.

Phosphuret.

2. Phosphuret of lead may be formed by mixing together equal parts of filings of lead and phosphoric glass, and then fusing them in a crucible. It may be cut with a knife, but separates into plates when hammered. It is of a silver white colour with a shade of blue, but it soon tarnishes when exposed to the air. This phosphuret may also be formed by dropping phosphorus into melted lead. It is composed of about 12 parts of phosphorus and 88 of lead †.

IV. Lead does not combine with azotic gas. Muriatic acid gradually corrodes it, and converts it into a white coloured oxide.

Alloys with

V. Lead is capable of combining with most of the metals.

gold,

1. Lead may be easily alloyed with gold by fusion. The colour of the gold is injured, and its ductility diminished. This alloy is of no use; but it is often formed in order to purify gold by cupellation.

Platinum,

2. Platinum and lead unite in a strong heat: the alloy is brittle, of a purplish colour, and soon changes on exposure to the air ‡. Many experiments have been made with this alloy, in order, if possible, to purify pla-

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* Kirwan's *Miner.* ii. 492 † Pelletier, *Ann. de Chim.* xiii. 114. ‡ Fourcroy.

tinum from other metals by cupellation, as is done successfully with silver and gold: But scarcely any of the experiments have succeeded; because platinum requires a much more violent heat to keep it in fusion than can be easily given.

Silver,

3. Silver is often alloyed with lead in order to purify it by cupellation. This alloy is very fusible, much softer than silver, and has much less tenacity, elasticity, and sonorousness: its colour is nearly that of lead, and its specific gravity greater than the mean density of the metals alloyed.

Mercury,

4. Mercury amalgamates readily with lead in any proportion, either by triturating it with lead filings, or by pouring it upon melted lead. The amalgam is white and brilliant, and, when the quantity of lead is sufficient, assumes a solid form. It is capable of crystallizing. The crystals are composed of one part of lead and one and a half of mercury *.

Copper,

5. Copper and lead may be easily combined by fusion. When the lead exceeds, the alloy is of a grey colour, and ductile while cold, but brittle when hot. It is employed sometimes for the purpose of making printers types for very large characters †.

Iron,

6. It was formerly supposed that lead does not combine with iron; but the experiments of Guyton Morveau have proved, that when the two metals are melted together, two distinct alloys are formed. At the bottom

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* Dijon Academicians.

† Fourcroy, vi. 266.—It has been lately ascertained by Messrs Cavendish and Hatchett, that copper cannot be used to alloy gold unless it be free from lead. The smallest portion of this metal, though too minute to affect the copper itself, produces a sensible change on the ductility of gold.

is found a button of lead containing a little iron; above is the iron combined with a small portion of lead *.

Tin.

7. Lead and tin may be combined in any proportion by fusion. This alloy is harder, and possesses much more tenacity than tin. Muschenbroeck informs us that these qualities are a maximum when the alloy is composed of 3 parts of tin and one of lead. What is called in this country *ley pewter* is often scarcely any thing else than this alloy. *Tinfoil*, too, almost always is a compound of tin and lead. This alloy, in the proportion of two parts of lead and one of tin, is more soluble than either of the metals separately. It is accordingly used by plumbers as a solder.

Affinities.

VI. The affinities of lead and of its oxides are as follows:

LEAD.	OXIDE OF LEAD.
Gold,	Sulphuric acid,
Silver,	Saclactic,
Copper,	Oxalic,
Mercury,	Arsenic,
Bismuth,	Tartaric,
Tin,	Muriatic,
Antimony,	Phosphoric,
Platinum,	Sulphurous,
Arsenic,	Suberic,
Zinc,	Nitric,
Nickel,	Fluoric,
Iron,	Citric,
Sulphur.	Lactic,
	Acetic,
	Boracic,
	Prussic,
	Carbonic.

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* *Ann. de Chim* xliii. 47.

The ancients gave to the seven metals last described (omitting *platinum*, which they did not know) the names of the planets, and denoted each of them by particular marks, which represented both the planet and the metal.

Names and marks given to the metals by the ancients.

Gold was the Sun, and represented by ☉
Silver . . . . Moon, ... ☽
Mercury . . . Mercury, ... ☿
Copper . . . Venus, ... ♀
Iron . . . . Mars, ... ♂
Tin . . . . . Jupiter, ... ♃
Lead . . . . Saturn, ... ♄

It seems most probable that these names were first given to the planets; and that the seven metals, the only ones then known, were supposed to have some relation to the planets or to the gods that inhabited them, as the number of both happened to be the same. It appears from a passage in Origen, that these names first arose among the Persians *. Why each particular metal

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* *Contra Celsum*, lib. vi. 22.—" Celsus de quibusdam Persarum mysteriis sermonem facit. Harum rerum, inquit, aliquod reperitur in Persarum doctrina Mithraicisque eorum mysteriis vestigium. In illis enim duæ cælestes conversiones, alia stellarum fixarum, errantium alia, et animæ per eas transitus quodam symbolo representantur, quod hujusmodi est Scala altas portas habens, in summa autem octava porta. Prima portarum plumbea, altera stannea, tertia ex ære, quarta ferrea, quinta ex ære mixto, sexta argentea, septima ex auro. *Κλιμαξ ὑψιπυλος, επι δ' αυτη πυλη ογδοη. Ἡ πρωτη των πυλων μολιβδου, ἡ δευτερα κασσιτερου, ἡ τριτη χαλκου, ἡ τεταρτη σιδηρου, ἡ πεμπτη καραςου νομισματος, ἡ ἑκτη αργυρου, χρυσου δ' ἡ ἑϐδομη.* Primum assignant Saturno tarditatem illius sideris plumbo indicantes: alteram Veneri, quam referunt, ut ipsi quidem putant, stanni splendor et mollities; tertiam Jovi, aheneam illam quidem et solidam: quartam Mercurio, quia Mercurius et ferrum, uterque operum omnium tolerantes, ad mercaturam utiles, laborum patientissimi. Marti quintam, inæqualem illam et variam propter mixturam.

was denominated by a particular planet it is not easy to see. Many conjectures have been made, but scarcely any of them are satisfactory.

Their supposed origin.

As to the characters by which these metals were expressed, astrologers seem to have considered them as the attributes of the deities of the same name. The circle, in the earliest periods among the Egyptians, was the symbol of divinity and perfection; and seems with great propriety to have been chosen by them as the character of the sun, especially as, when surrounded by small strokes projecting from its circumference, it may form some representation of the emission of rays. The semicircle is, in like manner, the image of the moon; the only one of the heavenly bodies that appears under that form to the naked eye. The character ♄ is supposed to represent the scythe of Saturn; ♃ the thunderbolts of Jupiter; ♂ the lance of Mars, together with his shield; ♀ the looking-glass of Venus; and ☿ the caduceus or wand of Mercury.

The alchymists, however, give a very different account of these symbols. Gold was the most perfect metal, and was therefore denoted by a circle. Silver approached nearest it; but as it was inferior, it was de-

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Sextam, quæ argentea est, lunæ; septimam auream soli tribuunt, quia solis et lunæ colores hæc duo metalla referunt."

Borrichius suspects, with a good deal of probability, that the names of the gods in this passage have been transposed by transcribers, either through ignorance or design. He arranges them as follows: "Secundam portam faciunt Jovis, comparantes ei stanni splendorem et mollitiem; tertiam Veneris æratam et solidam; quartam Martis. est enim laborum patiens, æque ac ferrum, celebratus hominibus; quintam Mercurii propter misturam inæqualem ac variam et quia negotiator est; sextam Lunæ argenteam; septimam Solis auream."—*Ol. Borrichius de ortu et progressu Chemiæ.* Hafniæ, 1668, 4to, p. 29.

noted only by a semicircle. In the character ☿ the adepts discovered gold with a silver colour. The cross at the bottom expressed the presence of a mysterious something, without which mercury would be silver or gold. This something is combined also with copper; the possible change of which into gold is expressed by the character ♀. The character ♂ declares the like honourable affinity also; though the semicircle is applied in a more concealed manner: for, according to the properest mode of writing, the point is wanting at the top, or the upright line ought only to touch the horizontal, and not to intersect it. Philosophical gold is concealed in steel; and on this account it produces such valuable medicines. Of tin, one half is silver, and the other consists of the unknown something; for this reason, the cross with the half moon appears in ♃. In lead this something is predominant, and a similitude is observed in it to silver. Hence in its character ♄ the cross stands at the top, and the silver character is only suspended on the right hand behind it.

Origin according to Beckmann.

Professor Beckmann, however, who has examined this subject with much attention, thinks that these characters are mere abbreviations of the old names of the planets. "The character of Mars (he observes *), according to the oldest mode of representing it, is evidently an abbreviation of the word Θουρος, under which the Greek mathematicians understood that deity; or, in other words, the first letter Θ, with the last letter ς placed above it. The character of Jupiter was originally the initial letter of Ζευς; and in the oldest manu-

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* *History of Inventions*, English Transl. iii. 67.

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scripts of the mathematical and astrological works of Julius Firmicus, the capital Z only is used, to which the last letter ς was afterwards added at the bottom, to render the abbreviation more distinct. The supposed looking-glass of Venus is nothing else than the initial letter distorted a little of the word Φωσφορος, which was the name of that goddess. The imaginery scythe of Saturn has been gradually formed from the two first letters of his name Κρονος, which transcribers, for the sake of dispatch, made always more convenient for use, but at the same time less perceptible. To discover in the pretended caduceus of Mercury the initial letter of his Greek name Στιλϐων, one needs only look at the abbreviations in the oldest manuscripts, where they will find that the Σ was once written as C; they will remark also that transcribers, to distinguish this abbreviation from the rest still more, placed the C thus ◡ , and added under it the next letter τ. If those to whom this deduction appears improbable will only take the trouble to look at other Greek abbreviations, they will find many that differ still farther from the original letters they express than the present character ☿ from the C and τ united. It is possible also that later transcribers, to whom the origin of this abbreviation was not known, may have endeavoured to give it a greater resemblance to the caduceus of Mercury. In short, it cannot be denied that many other astronomical characters are real symbols, or a kind of proper hieroglyphics, that represent certain attributes or circumstances, like the characters of Aries, Leo, and others quoted by Saumaise."

SECT. IX.

OF NICKEL.

History.

I. THERE is found in different parts of Germany a heavy mineral of a reddish brown colour, not unlike copper. When exposed to the air, it gradually loses its lustre, becomes at first brownish, and is at last covered with green spots. It was at first taken for an ore of copper; but as none of that metal can be extracted from it, the German miners gave it the name of *Kupfernickel*, or "false copper." Hierne, who may be considered as the father of the Swedish chemists, is the first person who mentions this mineral. He gives a description of it in a book published by him in 1694 on the art of detecting metals. It was generally considered by mineralogists as an ore of copper, till it was examined by the celebrated Cronstedt. He concluded from his experiments, which were published in the Stockholm Transactions for 1751 and 1754, that it contained a new metal, to which he gave the name of *nickel*.

This opinion was embraced by all the Swedes, and indeed by the greater number of chemical philosophers. Some, however, particularly Sage and Monnet, affirmed, that it contained no new metal, but merely a compound of various known metals, which could be separated from each other by the usual processes. These assertions induced Bergman to undertake a very laborious course of experiments, in order if possible to obtain *nickel* in a state of purity: for Cronstedt had not been able to separate a quantity of arsenic, cobalt, and iron, which adhered to it with much obstinacy. These experiments, which were published in 1775 *, fully confirmed the conclusions of Cronstedt. Bergman has shewn that nickel possesses peculiar properties; and that it can neither be reduced to any other metal, nor formed artificially by any combination of metals. It must therefore be considered as a peculiar metal. It may possibly be a compound, and so may likewise many other metals; but we must admit every thing to be a peculiar body which has peculiar properties, and we must admit every body to be simple till some proof be actually produced that it is a compound; otherwise we forsake the road of science, and get into the regions of fancy and romance. If any doubts still remained, they have been removed by the late experiments made by the *School of Mines* in Paris, which coincide exactly with those of Bergman.

Properties.

I. Nickel, when perfectly pure †, is of a fine white colour resembling silver; and, like that metal, it leaves a white trace when rubbed upon the polished surface of a hard stone ‡.

Its hardness is 8½, so that it is rather softer than iron. Its specific gravity is 9 §.

Its malleability, while cold, is rather greater than that of iron; but it cannot be heated without being oxidated, and in consequence rendered brittle ||.

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* Bergman, ii. 231.

† The method of obtaining the metals from their ores in a state of purity will be explained in the Second Part of this Work.

‡ Fourcroy, *Discours Preliminaire*, p. 117.

§ Bergman, ii. 267. and Fourcroy, Ibid.

|| Fourcroy, Ibid.

It is attracted by the magnet as strongly as iron. Like that metal, it may be converted into a magnet; and in that state points to the north when freely suspended precisely as a common magnetic needle *.

It requires for fusion a temperature at least equal to 150° Wedgewood †. It has not hitherto been crystallized.

Oxides.

II. When heated in an open vessel, it combines with oxygen, and assumes a green colour; and if the heat be continued, acquires a tinge of purple ‡. The oxide of nickel, according to Klaproth, is composed of 77 parts of nickel and 33 of oxygen §.

Union with combustibles.

III. Nickel has not been combined with carbon nor hydrogen; but it combines readily with sulphur and phosphorus.

Cronstedt found, that sulphuret of nickel may be easily formed by fusion. The sulphuret which he obtained was yellow and hard, with small sparkling facets; but the nickel which he employed was impure.

Phosphuret of nickel may be formed either by fusing nickel along with phosphoric glass, or by dropping phosphorus into it while red hot. It is of a white colour; and when broke it exhibits the appearance of very slender prisms collected together. When heated, the phosphorus burns, and the metal is oxidated. It is

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* Bergman, Klaproth, Fourcroy, Ibid.—Mr Chenevix had announced a method of procuring nickel which was not magnetic; but he afterwards ascertained, that it owed this peculiarity to the presence of arsenic.

† Bergman ii. 269.

‡ Fourcroy, *Discours Preliminaire*, p. 117.

§ Kirwan's *Miner.* ii. 490.

composed of 83 parts of nickel and 17 of phosphorus [*]. The nickel, however, on which this experiment was made, was not pure.

IV. Nickel is not acted upon by azote, nor does it combine with muriatic acid.

Alloys.

V. The alloys of this metal are but very imperfectly known.

With gold it forms a white and brittle alloy; with copper a white, hard, brittle alloy, easily oxidized when exposed to the air: with iron it combines very readily, and forms an alloy whose properties have not been sufficiently examined: with tin it forms a white, hard, brittle mass, which swells up when heated: with lead it does not combine without difficulty: with silver and mercury it refuses to unite: its combination with platinum has not been tried [†].

Affinities.

VI. The affinities of nickel, and its oxides, are, according to Bergman, as follows:

NICKEL.	OXIDE OF NICKEL.
Iron,	Oxalic acid,
Cobalt,	Muriatic,
Arsenic,	Sulphuric,
Copper,	Tartaric,
Gold,	Nitric,
Tin,	Phosphoric,
Antimony,	Fluoric,
Platinum,	Saclactic,
Bismuth,	Succinic,
Lead,	Citric,

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[*] Pelletier, *Ann. de Chim.* xiii. 135.

[†] Cronstedt.

Silver,
Zinc,
Sulphur,
Phosphorus.

Lactic,
Acetic,
Arsenic,
Boracic,
Prussic,
Carbonic,

SECT. X.

OF ZINC.

History.

I. THE ancients were acquainted with a mineral to which they gave the name of *Cadmia*, from Cadmus, who first taught the Greeks to use it. They knew that when melted with copper it formed brass; and that when burnt, a white spongy kind of ashes was volatilized, which they used in medicine *. This mineral contained a good deal of zinc; and yet there is no proof remaining that the ancients were acquainted with that metal †. It is first mentioned in the writings of Albertus Magnus, who died in 1280; but whether he had seen it is not so clear, as he gives it the name of *marcasite of gold*, which implies, one would think, that it

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* Pliny, lib. xxxiv. cap. 2. and 10.

† Grignon indeed says, that something like it was discovered in the ruins of an ancient Roman city in Champagne; but the substance which he took for it was not examined with any accuracy. It is impossible therefore to draw any inference whatever from his assertion. *Bulletin des fouilles d'une ville Romaine*, p. 11.

had a yellow colour *. The word *zinc* occurs first in the writings of Paracelsus, who died in 1541. He informs us very gravely, that it is a metal, and not a metal, and that it consists chiefly of the ashes of copper †. This metal has also been called *spelter*.

Zinc has never been found in Europe in a state of purity, and it was long before a method was discovered of extracting it from its ore ‡. Henkel pointed out one in 1721; Von Swab obtained it by distillation in

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* The passages in which he mentions it are as follows: They prove, I think incontestibly, that it was not the metal, but the ores of the metal, with which Albertus was acquainted. *De Mineral.* lib. ii. cap. 11. " Marchasita, sive marchasida ut quidam dicunt, est lapis in substantia, et habet multas species, quare colorem accipit cujuslibet metalli, et sic dicitur marchasita argentea et aurea, et sic dicitur aliis. Metallum tamen quod colorat eum non distillat ab ipso, sed evaporat in ignem, et sic relinquitur cinis inutilis, et hic lapis notus est apud alchimicos, et in multis locis veniuntur.

Lib. iii. cap. 10. " Æs autem invenitur in venis lapidis, et quod est apud locum qui dicitur Goselaria est purissimum et optimum, et toti substantiæ lapidis incorporatum, ita quod totus lapis est sicut marchasita aurea, et profundatum est melius ex eo quod purius.

Lib. v. cap. 5. " Dicimus igitur quod marchasita duplicem habet in sui creatione substantiam, argenti vivi scilicet mortificati, et ad fixionem approximantis, et sulphuris adurentis. Ipsam habere sulphureitatem comperimus manifesta experientia. Nam cum sublimatur, ex illa emanat substantia sulphurea manifesta comburens. Et sine sublimatione similiter perpenditur illius sulphureitas.

" Nam si ponatur ad ignitionem, non suscipit illam priusquam inflammatione sulphuris inflammetur, et ardeat. Ipsam vero argenti vivi substantiam manifestatur habere sensibiliter. Nam albedinem præstat Veneri meri argenti, quemadmodum et ipsum argentum vivum, et colorem in ipsius sublimatione cælestium præstare, et luciditatem manifestam metallicam habere videmus, quæ certum reddunt artificem Alchimiæ, illam has substantias continere in race sua.''

† See vol. vi. of his Works in quarto.

‡ The real discoverer of this method appears to have been Dr Isaa Lawson. See *Pott*, iii. diss. 7. and Watson's *Chemical Essays*.

1742; and Margraf published a process in the Berlin Memoirs in 1746 [*].

Properties.

1. Zinc is of a brilliant white colour, with a shade of blue, and is composed of a number of thin plates adhering together. When this metal is rubbed for some time between the fingers, they acquire a peculiar taste, and emit a very perceptible smell.

2. Its hardness is $6\frac{1}{2}$. When rubbed upon the fingers it tinges them of a black colour. Its specific gravity, after it has been melted, is 6.861; after it has been compressed, 7.1908 [†]; so that its density is increased $\frac{1}{20}$.

3. This metal forms as it were the limit between the brittle and the malleable metals. Its malleability is by no means to be compared with that of the metals already described; yet it is not brittle, like the metals which are to follow. When struck with a hammer, it does not break, but yields, and becomes somewhat flatter; and by a cautious and equal pressure, it may be reduced to pretty thin plates, which are supple and elastic, but cannot be folded without breaking. This property of zinc was first ascertained by Mr Sage [‡]. When heated to about 400°, it becomes so brittle, that it may be reduced to powder in a mortar.

4. It is not ductile. Its tenacity has not been ascertained.

5. When heated to the temperature of about 700° [§], it melts; and if the heat be increased, it evaporates, and may be easily distilled over in close vessels. When allowed to cool slowly, it crystallizes in small bundles of

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[*] Bergman, ii 309

[†] Brisson.

[‡] *Jour. de Min.* An. v. 595.

[§] Bergman.

quadrangular prisms, disposed in all directions. If they are exposed to the air while hot, they assume a blue changeable colour [*].

Oxides.

II. When exposed to the air, its lustre is soon tarnished, but it scarcely undergoes any other change. When kept under water its surface soon becomes black, the water is slowly decomposed, hydrogen gas is emitted, and the oxygen combines with the metal. If the heat be increased, the decomposition goes on more rapidly; and if the steam of water is made to pass over zinc at a very high temperature, it is decomposed so rapidly, that very violent detonations take place [†].

When zinc is kept melted in an open vessel, its surface is soon covered with a grey coloured pellicle, in consequence of its combination with oxygen. When this pellicle is removed, another soon succeeds it; and in this manner may the whole of the zinc be oxidated. When these pellicles are heated and agitated in an open vessel, they soon assume the form of a grey powder, often having a shade of yellow. This powder has been called the *grey oxide of zinc*. When zinc is raised to a very strong red heat in an open vessel, it takes fire, and burns with a brilliant white flame, and at the same time emits a vast quantity of very light white flakes. These are merely an *oxide of zinc*. This oxide was well known to the ancients. Dioscorides describes the method of preparing it. The ancients called it *pompholyx*: the early chemists gave it the name of *nihil album*, *lana philosophica*, and *flowers of zinc*. Dioscorides compares it to wool [‡].

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[*] Mongez.

[†] Lavoisier.

[‡] Εριων τολυπαις ἀφομοιονται. V. 85. p. 352.

Two different oxides of zinc are at present known.

Peroxide.

1. The peroxide, or white oxide of zinc, is the oxide usually formed in the different processes to which the metal is subjected. We are indebted to Mr Proust for an exact analysis of this oxide and its combinations. It is composed of 80 parts of zinc and 20 of oxygen [*]. It may be formed not only by burning zinc, but also by dissolving it in diluted sulphuric or nitric acid, and precipitating it by potass. This oxide is used as a paint; but its colour must be perfectly white. When zinc happens to contain a little iron, which is often the case with the zinc of commerce, the oxide obtained has a tinge of yellow, because it is mixed with a little yellow oxide of iron.

Protoxide.

2. The protoxide, or zinc combined with a minimum of oxygen, is obtained by exposing the peroxide to a strong heat in an earthen ware retort or covered crucible. From the experiments of Desormes and Clement, it appears that by this process the zinc loses a portion of its oxygen, and assumes a yellow colour. According to the analysis of these chemists, the protoxide of zinc is composed of 88 parts zinc and 12 parts of oxygen [†].

3. The reduction of the oxides of zinc is an operation of difficulty, in consequence of the strong affinity which exists between zinc and oxygen. It must be mixed with charcoal, and exposed to a strong heat in vessels which screen it from the contact of the external air.

Union with combustibles.

III. Most of the simple combustibles combine with zinc.

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[*] *Ann. de Chim.* xxxv. 51.

[†] *Ibid.* xxxix. 32.

Solution in hydrogen gas.

1. Hydrogen gas dissolves a little of it in certain situations. It is usual to procure hydrogen gas, by dissolving zinc in diluted sulphuric acid. The gas thus obtained is as pure as any which can be procured. It carries along with it, however, a little zinc in solution; but it deposits it again upon the sides of the glass jars, and on the surface of the water over which it stands. This gas, if we believe the French chemists, contains often a little carbureted hydrogen gas *; a proof that zinc frequently contains carbon. When this metal is dissolved in sulphuric acid, it deposits a black insoluble powder, which the French chemists found to be carburet of iron †. It is uncertain whether it be this carburet, or carbon combined with zinc, which gives occasion to the production of the carbureted hydrogen gas.

Sulphuret.

2. It is believed at present that sulphur does not combine with zinc in the metallic state; because no attempt to form the combination artificially has succeeded. Sulphur unites with the oxide of zinc when melted along with it in a crucible. This was first discovered by Dehne in 1781 ‡. The experiment was afterwards repeated by Morveau §. The sulphureted oxide of zinc is of a dark brown colour, and brittle. It exists native in great abundance, and is known by the

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* The presence of this gas in hydrogen gas from zinc, was inferred by the French chemists, because, when the hydrogen gas is burnt, some carbonic acid gas is found among the air, which remains unconsumed.

† Proust has ascertained, that this black powder is often not carburet of iron, but a mixture of arsenic, copper, and lead. *Ann. de Chim.* xxxv. 51.

‡ *Chem. Journ.* p. 46. and Crell's *Annals*, 1786, i. 7.

§ *Mem. de l'Acad. de Dijon*, 1783.

name of *blende*. Mr Proust, however, has announced it as his opinion, that *blende* is a sulphuret of zinc, or a compound of sulphur and zinc in the metallic state *.

Phosphuret,

3. Zinc may be combined with phosphorus, by dropping small bits of phosphorus into it while in a state of fusion. Pelletier, to whom we are indebted for the experiment, added also a little resin, to prevent the oxidation of the zinc. Phosphuret of zinc is of a white colour, a metallic splendor, but resembles lead more than zinc. It is somewhat malleable. When hammered or filed, it emits the odour of phosphorus. When exposed to a strong heat, it burns like zinc †.

Phosphureted oxide.

4. Phosphorus combines also with the oxide of zinc; a compound which Margraf had obtained during his experiments on phosphorus. When 12 parts of oxide of zinc, 12 parts of phosphoric glass, and 2 parts of charcoal powder, are distilled in an earthen ware retort, and a strong heat applied, a metallic substance sublimes of a silver white colour, which when broken has a vitreous appearance. This, according to Pelletier, is phosphureted oxide of zinc. When heated by the blow pipe, the phosphorus burns, and leaves behind a glass, transparent while in fusion, but opaque after cooling ‡.

Phosphureted oxide of zinc is obtained also when two parts of zinc and one part of phosphorus are distilled in an earthen retort. The products are, 1. Zinc; 2. Oxide of zinc; 3. A red sublimate, which is phosphureted oxide of zinc; 4. Needleform crystals, of

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* *Jour. de Phys.* lvi. 79.

† *Ann. de Chim.* xiii. 129.

‡ Pelletier, *Ibid.* 128.

metallic brilliancy, and a bluish colour. These also Pelletier considers as phosphureted oxide of zinc *.

IV. Zinc does not combine with azote. Muriatic acid readily converts it into an oxide.

Alloys with

V. Zinc combines with almost all the metals, and some of its alloys are of great importance.

Gold,

1. It may be united to gold in any proportion by fusion. The alloy is the whiter and the more brittle the greater quantity of zinc it contains. An alloy, consisting of equal parts of these metals, is very hard and white, receives a fine polish, and does not tarnish readily. It has therefore been proposed by Mr Malouin † as very proper for the specula of telescopes. One part of zinc is said to destroy the ductility of 100 parts of gold ‡.

Platinum,

2. Platinum combines very readily with zinc. The alloy is brittle, pretty hard, very fusible, of a bluish white colour, not so clear as that of zinc §.

Silver,

3. The alloy of silver and zinc is easily produced by fusion. It is brittle, and has not been applied to any use.

Mercury,

4. Zinc may be combined with mercury, either by triturating the two metals together, or by dropping mercury into melted zinc. This amalgam is solid. It crystallizes when melted and cooled slowly into lamellated hexagonal figures, with cavities between them. They are composed of one part of zinc and two, and a half of mercury ||. It is used to rub on electrical machines, in order to excite electricty.

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* *Ann. de Chim.* xiii. 125.

† *Mem. Acad. Par.* 1742.

‡ Keir's *Macquer's Dictionary.*

§ Dr Lewis.

|| *Elemens de Chim. Dijon*, t. 3.

Copper,

5. Zinc combines readily with copper, and forms one of the most useful of all the metallic alloys. The metals are usually combined together by stratifying plates of copper and a native oxide of zinc combined with carbonic acid, called *calamine*, and applying heat. When the zinc does not exceed a fourth part of the copper, the alloy is known by the name of *brass*. It is of a beautiful yellow colour, more fusible than copper, and not so apt to tarnish. It is malleable, and so ductile that it may be drawn out into wire. Its density is greater than the mean. It ought to be by calculation 7.6296, but it actually is 8.3958; so that its density is increased by about $\frac{1}{10}$th. When the alloy contains three parts of zinc and four of copper, it assumes a colour nearly the same with gold, but it is not so malleable as brass. It is then called *pinchbeck*, *prince's metal*, or *Prince Rupert's metal*. Brass was known, and very much valued by the ancients. They used an ore of zinc to form it, which they called *cadmia*. Dr Watson has proved that it was to brass which they gave the name of *orichalcum**. Their *æs* was copper or rather bronze†.

Brass.

Pinchbeck.

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* *Manchester Transactions*, vol. ii. p. 47.

† The ancients do not seem to have known accurately the difference between copper, brass, and bronze. Hence the confusion observable in their names. They considered brass as only a more valuable kind of copper, and therefore often used the word *æs* indifferently to denote either. It was not till a late period that mineralogists began to make the distinction. They called copper *æs cyprium*, and afterwards only *cyprium*, which in process of time was converted into *cuprum*. When these changes took place is not known accurately. Pliny uses *cyprium*, lib. xxxvi. cap. 26. The word *cuprum* occurs first in Spartian, who lived about the year 290. He says, in his life of Caracalla, *cancelli ex ære vel cupro.*

Iron,

6. It is very difficult to form an alloy of iron and zinc. Wallerius has shewn that iron is capable of combining with a small proportion of zinc; and Malouin has shewn that zinc may be used instead of tin to cover iron plates; a proof that there is an affinity between the two metals *.

Tin,

7. Tin and zinc may be easily combined by fusion. The alloy is much harder than zinc, and scarcely less ductile. This alloy is often the principal ingredient in the compound called *pewter*.

Lead.

8. The alloy of lead and zinc has been examined by Wallerius, Gellert, Muschenbroeck, and Gmelin. This last chemist succeeded in forming the alloy by fusion. He put some suet into the mixture, and covered the crucible in order to prevent the evaporation of the zinc. When the zinc exceeded the lead very much, the alloy was malleable, and much harder than lead. A mixture of two parts of zinc and one of lead formed an alloy more ductile and harder than the last. A mixture of equal parts of zinc and lead formed an alloy differing little in ductility and colour from lead; but it was harder, and more susceptible of polish, and much more sonorous. When the mixture contained a smaller quantity of zinc, it still approached nearer the ductility and colour of lead, but it continued harder, more sonorous, and susceptible of polish, till the proportions approached to 1 of zinc and 16 of lead, when the alloy differed from the last metal only in being somewhat harder†.

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* *Mem. Par.* 1742.

† *Ann. de Chim.* ix. 95.

9. Zinc does not appear capable of combining with nickel by fusion *.

Affinities.

VI. The affinities of zinc and its oxides are as follows:

ZINC.	OXIDE OF ZINC.
Copper,	Oxalic acid,
Antimony,	Sulphuric,
Tin,	Muriatic,
Mercury,	Saclactic,
Silver,	Nitric,
Gold,	Tartaric,
Cobalt,	Phosphoric,
Arsenic,	Citric,
Platinum,	Succinic,
Bismuth,	Fluoric,
Lead,	Arsenic,
Nickel,	Lactic,
Iron.	Acetic,
	Boracic,
	Prussic,
	Carbonic,

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* The Chinese, however, seem to be in possession of some method of combining these metals: For, according to Engestroem, the *pak-fong*, or white copper, is composed of copper, nickel, and zinc. The zinc amounts to seven-sixteenths of the whole, and the proportions of the copper and nickel are to each other as five to thirteen. *Mem. Stock.* 1776.

SECT. XI.

OF BISMUTH.

History.

I. THE ancients were acquainted with bismuth, but they confounded it with tin. It is mentioned occasionally by the alchymists and earlier mineralogists; and referred sometimes to tin, sometimes to lead, and sometimes to antimony. The German miners gave it the name of *lectum argenti;* and appear to have considered it as silver beginning to form, and not yet completed[*]. It is mentioned as a peculiar metal by Stahl, Dufay, and other chemists who wrote about the beginning of the 18th century. But Pott, and Geoffroy junior[†], were the first who examined it with attention, and published an account of its peculiar properties.

Properties.

1. Bismuth is of a reddish white colour, and almost destitute both of taste and smell. It is composed of broad brilliant plates adhering to each other. The figure of its particles, according to Hauy, is an octahedron, or two four-sided pyramids, applied base to base[‡].

2. Its hardness is 7. Its specific gravity is 9.8227[§].

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[*] Konig's *Regnum Minerale*, p. 80. Even so late as the end of the 17th century it was considered as a species of lead. There are three kinds of lead, says Ettmuller; namely, common lead, tin, and bismuth. Bismuth approaches nearest to silver. Ettmuller's *Chemistry*, p. 321.

[†] *Mem. Par.* 1753, p. 296.

[‡] *Jour. de Min.* An. v. p. 582.

[§] Brisson.

3. When hammered cautiously, its density, as Muschenbroeck ascertained, is considerably increased. It is not therefore very brittle; it breaks, however, when struck smartly by a hammer, and consequently is not malleable. Neither can it be drawn out into wire. Its tenacity has not been ascertained.

4. When heated to the temperature of 460°*, it melts; and if the heat be much increased, it evaporates, and may be distilled over in close vessels. When allowed to cool slowly, and when the liquid metal is withdrawn, as soon as the surface congeals it crystallizes in parallelopipeds, which cross each other at right angles.

II. When exposed to the air, it soon loses its lustre, but scarcely undergoes any other change. It is not altered when kept under water.

Oxides.

Only two oxides of bismuth are at present known. But the combination of this metal with oxygen has been more neglected by chemists than almost any other.

1. When kept melted in an open vessel, its surface is soon covered with a dark blue pellicle; when this is removed, another succeeds, till the whole metal is oxidized. When these pellicles are kept hot and agitated in an open vessel, they are soon converted into a brownish powder, known by the name of *brown oxide*. This is the protoxide of bismuth. According to Fourcroy, it is composed of 90 parts of bismuth and 10 of oxygen

2. When bismuth is raised to a strong red heat, it takes fire and burns with a faint blue flame, and emits

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* Lewis.

a yellow smoke. When this is collected, it is a yellow powder, not volatile, which has been called *yellow oxide of bismuth*.

When bismuth is dissolved in nitric acid, if water be poured into the solution, a white powder precipitates, which was formerly called *magistry of bismuth*, and at present *white oxide of bismuth*. According to the experiments of Klaproth, it is composed of 81.3 parts bismuth and 17.7 of oxygen*. This oxide is used as a paint under the name of *pearl white*. It is more than probable that both the white and the yellow oxides of bismuth are the same peroxide, and that the different shades of colour is owing to the different modes of preparing them.

3. The oxides of bismuth are very easily converted into glass; for that reason bismuth is sometimes used in the process of cupellation instead of lead. It was first proposed for that purpose by Dufay in 1727, and his experiments were afterwards confirmed by Pott.

4. These oxides are easily reduced when heated along with charcoal or other combustible bodies; for the affinity between bismuth and oxygen is but weak.

Union with combustibles.

III. Bismuth has not been combined with carbon nor hydrogen. Neither does it seem capable of combining in any notable proportion with phosphorus. Mr Pelletier attempted to produce the phosphuret of bismuth by various methods without success. When he dropped phosphorus, however, into bismuth in fusion, he obtained a substance which did not apparently differ from bismuth, but which, when exposed to the blow-

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[*] Klaproth's *Beitrage*, ii. 294.

pipe, gave evident signs of containing phosphorus *. This substance, according to Pelletier, did not contain above four parts in the hundred of phosphorus, and even this small portion seems only to have been mechanically mixed.

Sulphuret.

2. Sulphur combines readily with bismuth by fusion. The sulphuret of bismuth is of a bluish grey colour, and crystallizes into beautiful tetrahedral needles. It is composed of 85 parts of bismuth and 15 of sulphur †. This sulphuret is much less fusible than bismuth. The sulphur is not disengaged except by a strong and long continued heat.

Alloys with

V. Bismuth combines with almost all the metals, but few of its alloys are much used.

Gold,

1. Equal parts of bismuth and gold form a brittle alloy, nearly of the same colour with bismuth ‡; the specific gravity of which is greater than the mean.

Platinum,

2. The alloy of bismuth and platinum is also very brittle. When exposed to the air, it assumes a purple, violet, or blue colour. The bismuth can scarcely be separated by heat §.

Silver,

3. Bismuth combines readily with silver by fusion. The alloy is brittle, lamellar, and nearly of the colour of bismuth. This alloy is sometimes formed, in order to purify silver by the process of cupellation.

Mercury,

4. Mercury combines readily with bismuth, either by triturating the metals together, or by pouring two parts of hot mercury into one part of melted bismuth. This amalgam is at first soft, but it becomes gradually

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* *Ann. de Chim.* xiii. 130.

† Wenzel, Kirwan's *Min.* ii. 492.

‡ Keir, Macquer's *Dictionary.*

§ Dr Lewis.

hard. When melted and cooled slowly, it crystallizes [*]. When the quantity of mercury exceeds the bismuth considerably, the amalgam remains fluid, and has the property of dissolving lead and rendering it also fluid [†]. This triple compound may be filtered through shamoy leather without decomposition. Mercury is sometimes adulterated with these metals; but the imposition may be easily detected, not only by the specific gravity of the mercury, which is too small, but because it *drags a tail*, as the workmen say; that is, when a drop of it is agitated on a plain surface, the drop does not remain spherical, but part of it adheres to the surface, as if it were not completely fluid, or as if it were inclosed in a thin pellicle.

Copper, 5. Copper forms with bismuth a brittle alloy of a pale red colour, and a specific gravity exactly the mean of that of the two metals alloyed [‡].

Iron, 6. Bismuth combines but imperfectly with iron [§]. The alloy is brittle, and attracted by the magnet even when the bismuth amounts to ¾ths of the whole [||] The specific gravity of this alloy is less than the mean [¶].

Tin, 7. Bismuth and tin unite readily. A small portion of bismuth increases the brightness, hardness, and sonorousness of tin: it often enters into the composition of *pewter*, though never in Britain. Equal parts of tin and bismuth form an alloy that melts at 280°: eight parts of tin and one of bismuth melt at 390°: two parts of tin and one of bismuth at 330° [**].

Lead, 8. The alloy of lead and bismuth is of a dark grey

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[*] Pott.

[†] Cramer.

[‡] Gellert.

[§] Muschenbroeck.

[||] Henkel.

[¶] Gellert.

[**] Dr Lewis.

colour and close grain [*]. It is ductile, unless the bismuth exceeds the lead considerably [†]. Bismuth increases the tenacity of lead prodigiously. Muschenbroeck found, that the tenacity of an alloy composed of three parts of lead and two of bismuth was ten times greater than that of pure lead. The specific gravity of this alloy is geater than the mean [‡].

9. When eight parts of bismuth, five of lead, and three of tin, are melted together, a white coloured alloy is obtained, which melts at the temperature of 212°, and therefore remains fusible under boiling water.

Nickel.

10. The alloy of bismuth and nickel is brittle, and formed of thin plates [§].

11. Bismuth does not combine with zinc.

VI. The affinities of bismuth and of its oxides are, according to Bergman, as follows:

Affinities.

BISMUTH.	OXIDE OF BISMUTH.
Lead,	Oxalic acid,
Silver,	Arsenic,
Gold,	Tartaric,
Mercury,	Phosphoric,
Antimony,	Sulphuric,
Tin,	Muriatic,
Copper,	Nitric,
Platinum,	Fluoric,
Nickel,	Saclactic,
Iron,	Succinic,
Sulphur.	Citric,
	Lactic,
	Acetic,
	Prussic,
	Carbonic.

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[*] Wallerius.

[†] Baumé.

[‡] Gellert.

[§] Cronstedt.

Book I.
Division I.

SECT. XII.

OF ANTIMONY.

History.

I. THE ancients were acquainted with an oxide of antimony to which they gave the names of στιμμι and *stibium*. Pliny * informs us, that it was found in silver ore; and we know that at present there are silver ores † in which it is contained. It was used as an external application to sore eyes; and Pliny gives us the method of preparing it ‡. It is probable that a dark bluish grey mineral, of a metallic lustre, was also known to them by the same names. It certainly bore these names as early at least as the 8th century. This mineral is composed of the metal now called *antimony* and sulphur; but it was known by the name of *antimony* ever since the days of Basil Valentine till very lately. The metal itself, after it was discovered, was denominated *regulus of antimony*. The Asiatic ‖ and Grecian ladies employed this mineral to paint their eyebrows black. But it does not appear that the ancients considered this substance as containing a metal, or that they knew our antimony in a state of purity §. Who first extracted it

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[*] Pliny, lib. xxxiii. cap. 6.

[†] Kirwan's *Miner.* ii. 110.

[‡] Pliny, Ibid.

[‖] 2 Kings, ix. 30. and Ezek. xxiii. 40.

[§] Mr Roux indeed, who at the request of Count Caylus analysed an ancient mirror, found it composed of copper, lead, and antimony. This would go far to convince us that the ancients knew this metal, provided it could be proved that the mirror was *really* an ancient one; but this point appears to be extremely doubtful.

from its ore we do not know; but Basil Valentine is the first who describes the process. To his *Currus Triumphalis Antimonii*, published towards the end of the 15th century, and to the exertions of those medical alchymists who followed his career, we are indebted for almost all the properties of this substance.

No metal, not even mercury nor iron, has attracted so much of the attention of physicians as antimony. One party extolled it as an infallible specific for every disease: while another descried it as a most virulent poison, which ought to be expunged from the list of medicines. Lemeri, about the end of the 17th century, was the first chemist who attempted a rational account of its properties; and Meuder, in 1738, published the first accurate analysis of its ores*. But the number of writers who have made this metal their particular study is so great, that it would be in vain to attempt even a list of their names. Bergman, Berthollet, Thenard, and Proust, are the modern chemists who have thrown the greatest light upon its properties†.

Properties.

1. Antimony is of a greyish white colour, and has a good deal of brilliancy. Its texture is laminated, and exhibits plates crossing each other in every direction,

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[*] *Analyſis Antimonii Phyſico-chim. rationalis.*

[†] The word *alcohol*, which is still employed in chemistry, was, if we believe Homerus Poppius Thallinus, first applied to this mineral. "Hispanicis mulierculis ejus usus in ciliorum pulchritudine concilianda fuit usitatissimus: pulverem autem vocabant alcohol (quæ vox etiam adhuc in Hermeticorum laboratoriis sonat) unde antimonium crudum et nondum contusum piedra de alcohol nominarunt." It was known among the alchymists by a great variety of absurd names; such as, *Ctbia*, *alkoſol*, *alcoſol*, *aries*, *ſaturnus philoſophorum*, *magneſia ſaturni*, *filius* and *nepbus ſaturni*.

and sometimes assuming the appearance of imperfect crystals. Hauy has with great labour ascertained that the primitive form of these crystals is an octahedron, and that the integrant particles of antimony have the figure of tetrahedrons *. When rubbed upon the fingers, it communicates to them a peculiar taste and smell.

2. Its hardness is 6½. Its specific gravity is, according to Brisson, 6.702; according to Bergman, 6.86.

3. It is very brittle, and may be easily reduced in a mortar to a fine powder. Its tenacity has not been tried.

4. When heated to 809° Fahrenheit, or just to redness, it melts. If after this the heat be increased, the metal evaporates. On cooling, it assumes the form of oblong crystals, perpendicular to the internal surface of the vessel in which it cools. It is to this crystallization that the laminated structure which antimony always assumes is owing.

Oxides.

II. When exposed to the air, it undergoes no change except the loss of its lustre. Neither is it altered by being kept under water. But when steam is made to pass over red hot antimony, it is decomposed so rapidly that a violent detonation is the consequence †.

When heated in an open vessel, it gradually combines with oxygen, and evaporates in a white vapour. This vapour, when collected, constitutes a white coloured oxide, formerly called *argentine flowers of antimony*. When raised to a white heat, and suddenly agitated, antimony burns, and is converted into the same white coloured oxide.

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* *Jour. de Min.* An.v. 601.

† Fourcroy, v. 228.

According to Thenard *, who published an excellent dissertation on antimony some time ago, this metal is capable of combining with no less than six different doses of oxygen, and of forming six oxides, which may be exhibited in a separate state. But his method of obtaining most of these bodies, namely, by the application of heat, does not seem capable of leading to any very precise result; while at the same time several of his oxides differ from each other only by 1 or 2 hundredth parts of oxygen; a degree of precision much greater than chemists are able at present to attain. Proust has lately examined this important question, and has found antimony capable of forming only two oxides, agreeing in this respect with most of the other metals.

Protoxide.

1. The protoxide of antimony may be obtained by the following process. Dissolve antimony in muriatic acid, and dilute the solution with water: a white precipitate appears, composed of the protoxide of antimony, combined with a little muriatic acid †. Wash this precipitate with water, and then boil it for some time in a solution of *carbonat of potass*. Then wash it well and dry it on a filter ‡.

The protoxide thus procured is of a dirty white colour, without any lustre. When raised to a moderate red heat it melts, and may be kept for a long time in fusion in a retort. When allowed to cool, its surface becomes covered with small opaque crystals lying close to-

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* *Ann. de Chim.* xxxii. 259.

† The white powder thus obtained, was formerly called *powder of* Agaroth, from Victor Algarothi, a physician in Verona, who first procured it in that manner from muriat of antimony.

‡ Proust, *Jour. de Phys.* lv. 328.

gether, and of a yellowish white colour. It is indeed extremely fusible, and always becomes opaque on cooling. A part of it is volatilized with a moderate heat, provided air be present. It is composed of

81.5	antimony
18.5	oxygen
100.0	

This oxide may be kept melted in contact with antimony any length of time without alteration *.

Peroxide.

2. The peroxide of antimony may be obtained by exposing the metal in the open air to a violent heat: it takes fire, and a white oxide is sublimed, formerly called *argentine flowers of antimony*. It is obtained also by causing nitric acid to act upon antimony, and by throwing the metal into red hot nitre. After the combustion there remains in the crucible a white mass, consisting of the oxide of antimony, combined with the potass of the nitre. Water dissolves a part of this compound: when an acid is poured into this solution, a white powder precipitates, which is the peroxide of antimony.

This oxide is of a white colour; it is insoluble in water, and not nearly so soluble in acids as the protoxide. Neither is it so fusible as that oxide, requiring a pretty violent heat; but it is volatilized at a lower temperature, forming white prismatic crystals of a silvery lustre. It is composed of 77 antimony

23 oxygen

100

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* Proust, *Jour. de Phys.* lv. 328.

When melted with a fourth part of antimony, the whole is converted into protoxide *.

Union with combustibles.

III. Antimony has never been combined with carbon nor hydrogen. When its oxides are heated along with charcoal or oils, they are reduced, but imperfectly, unless some body (as potass) be present to favour the fusion of the metal. The greater part remains in the state of a black spongy mass, which often takes fire when exposed to the air. Antimony combines readily with sulphur and with phosphorus.

Sulphuret.

1. Sulphuret of antimony may be formed by mixing its two component parts together, and fusing them in a crucible. It has a dark bluish grey colour, with a lustre approaching the metallic; it is much more fusible than antimony, and may be crystallized by slow cooling. It is composed, according to Bergman, of 74 parts of antimony and 26 of sulphur †. With this estimate the late experiments of Proust coincide almost exactly. According to that very accurate chemist, sulphuret of antimony is composed of 75.1 antimony
24.9 sulphur

100.0 ‡

This substance is found native in great abundance, and indeed is almost the only ore of antimony. It was to this sulphuret that the term *antimony* was applied by the earlier chemists; the pure metal was called *regulus of antimony* §.

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[*] Proust, *Jour. de Phys.* lv. 328.

[†] Berg. iii. 167.

[‡] *Jour. de Phys.* lv. 325.

[§] Sulphuret of antimony is sometimes used to separate the baser metals from gold. When heated along with gold, it carries off all the other metals, while part of the antimony combines with the gold. This is re-

Glass of antimony.

2. The protoxide of antimony has the property of dissolving different proportions of sulphuret when in a state of fusion. The resulting compound is a semitransparent substance of a brownish red colour, differing considerably in its appearance according to the proportion of its ingredients. When it is composed of about 8 parts of oxide and 1 part of sulphuret, it has a red colour, and is semitransparent. It is then called *glass of antimony*. When it contains 8 parts oxide and 2 sulphuret it is opaque, and of a red colour inclining to yellow. This is the *crocus metallorum* of apothecaries. Eight parts of oxide and 4 of sulphuret form an opaque mass of a dark red colour. This is the *liver of antimony* of apothecaries *.

When sulphur is heated with either of the oxides, it reduces them to the metallic state if sufficient in quantity; if too small for that it deoxidates a portion, combines with it, and the sulphuret formed unites with the remaining oxide, always converted to a protoxide. Hence the reason that these different compounds may be formed by a great variety of processes. The glass of antimony is usually prepared by exposing sulphuret of antimony in powder to a gentle heat for a considerable time in an open vessel. By this process, which is called *roasting*, the greater part of the sulphur is driven off, and the metal is reduced to a protoxide. In this state it is put into a crucible, and melted by a sudden heat into glass. If the roasting has been carried so far

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moved by oxidating the gold by means of heat and nitre. This property of sulphuret of antimony induced the alchymists to give it the name of the *wolf*, quia ferocia sua omnia metalla præter leonem, h. e. aurum, absumit. *Homeri Poppii* [illegible] *antimonii*, c. 1.

* Proust, *Jour. de Phys.* lv. 334.

as to drive off the whole of the sulphur, only dark coloured scoriæ are obtained; but on the addition of a little sulphur or sulphuret of antimony, the glass may be easily formed *. The glass sold by apothecaries is seldom or never pure, containing almost always, as Vauquelin has demonstrated, about 0.09 † parts of silica ‡; derived undoubtedly from the crucibles in which the oxidated sulphuret is fused; for these crucibles contain a very great proportion of siliceous earth.

The peroxide of antimony is incapable of dissolving any sulphuret. Of course it does not form a glass.

Phosphuret,

3. When equal parts of antimony and phosphoric glass are mixed together with a little charcoal powder, and melted in a crucible, phosphuret of antimony is produced. It is of a white colour, brittle, appears laminated when broken, and at the fracture a number of small cubic facettes are observable. When melted it emits a green flame, and the white oxide of antimony sublimes. Phosphuret of antimony may likewise be prepared by fusing equal parts of antimony and phosporic glass, or by dropping phosphorus into melted antimony §.

IV. Antimony does not combine with azote, nor with muriatic acid.

Alloys with

V. Antimony combines readily with most of the metals; but the greater number of its alloys have not been applied to any use.

Gold,

1. Antimony and gold may be combined by fusion, and form a brittle compound of a yellow colour. Great attention was paid to this alloy by the alchymists, who

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* Berg. iii. 166.

† *Ann. de Chim.* xxxiv. 139.

‡ An *earth* which will be described in the next Book.

§ Pelletier, *Ann. de Chim.* xiii. 132.

affirmed that the quantity of gold might be increased by alloying it with gold and then purifying it [*].

Platinum,

2. Platinum easily combines with antimony. The alloy is brittle, and much lighter than platinum [†]. The antimony cannot afterwards be completely separated by heat.

Silver,

3. Silver may be alloyed with antimony by fusion. The alloy is brittle, and its specific gravity, as Gellert has observed [‡], is greater than intermediate between the specific gravities of the two metals which enter into it.

Mercury,

4. Antimony does not amalgamate with mercury while cold. When three parts of mercury are mixed with one part of melted antimony, a soft amalgam is obtained, which very soon decomposes of itself [§]. Gellert also succeeded in forming this amalgam [||].

Copper,

5. Copper combines readily with antimony by fusion. The alloy, when it consists of equal parts of the two metals, is of a beautiful violet colour, and its specific gravity is greater than intermediate [¶]. This alloy was called *regulus of Venus* by the alchymists.

Iron,

6. Iron combines with antimony by fusion, and forms a brittle hard alloy, the specific gravity of which is less than intermediate. The magnetic quality of iron is much more diminished by being alloyed with antimony than with most other metals [**]. This alloy may be obtained also by fusing in a crucible two parts of sul-

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[*] This made them give antimony the name of *balneum regale*. The cause of their mistake is obvious: they did not separate the whole of the antimony from the gold; hence the increase of weight.

[†] Dr Lewis.

[‡] *Metallurgic Chemistry*, p. 136.

[§] Wallerius.

[||] *Metall. Chim.* p. 141.

[¶] Gellert, p. 136.

[**] Ibid.

phuret and one of iron. It was formerly called *martial regulus*.

Tin,

7. The alloy of tin and antimony is white and brittle; its specific gravity is less than intermediate *. This alloy is employed for different purposes; particularly for making the plates on which music is engraved †.

Lead,

8. When equal quantities of lead and antimony are fused, the alloy is porous and brittle: three parts of lead and one of antimony form a compact alloy, malleable, and much harder than lead: 12 parts of lead and one of antimony form an alloy very malleable, and a good deal harder than lead: 16 parts of lead and one of antimony form an alloy which does not differ from lead except in hardness. This alloy forms printers types. Its tenacity is very considerable §, and its specific gravity is greater than the mean ||.

Zinc,

9. Zinc may be readily combined with antimony by fusion. The alloy is hard and brittle, and has the colour of steel. Its specific gravity is less than intermediate ¶.

Bismuth.

10. Antimony forms a brittle alloy with bismuth; to manganese it unites but imperfectly **: the compounds which it forms with nickel and cobalt have not been examined.

VI. The affinities of antimony, and of its oxides, are, according to Bergman, as follows:

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* Gellert, p. 136.

† Fourcroy, vi. 25.

‡ Gmelin, *Ann. de Chim.* viii. 319.

§ Muschenbroeck.

|| Gellert, p. 136.

¶ Gellert, ibid.

** Gmelin, *Ann. de Chim.* xix. 367.

Affinities.

ANTIMONY.	OXIDE OF ANTIMONY.
Iron,	Muriatic,
Copper,	Oxalic,
Tin,	Sulphuric,
Lead,	Nitric,
Nickel,	Tartaric,
Silver,	Saclactic,
Bismuth,	Phosphoric,
Zinc,	Citric,
Gold,	Succinic,
Platinum,	Fluoric,
Mercury,	Arsenic,
Arsenic,	Lactic,
Cobalt,	Acetic,
Sulphur.	Boracic,
	Prussic,
	Carbonic.

SECT. XIII.

OF TELLURIUM.

History.

I. THE mine of Mariahilf, in the mountains of Fatzbay near Zalethna in Transylvania, contains an ore of a bluish white colour and a metallic lustre, concerning the nature of which mineralogists were for a long time doubtful. That it contained a little gold was certain; but by far the greatest part of it consists of a metallic substance, which some supposed to be bismuth, others antimony. Muller of Reichenstein examined it in 1782*, and concluded, from his experiments, that this ore, which had been distinguished by the names of *aurum problematicum*, *aurum paradoxicum*, and *aurum album*, contains a new metal different from every other. Being still dissatisfied with his own conclusions, he sent a specimen of it to Bergman; but the specimen was too small to enable that illustrious chemist to decide the point. He ascertained, however, that the metal in question is not antimony. The experiments of Muller appeared so satisfactory, that they induced Mr Kirwan, in the second edition of his *Mineralogy*, published in 1796, to give this metal a separate place, under the name of *sylvanite*. Klaproth published an analysis of the ore in 1798, and completely confirmed the conclusions of Muller †. To the new metal, which constitutes 0.925 of the ore, he gave the name of *tellurium*; and this name has been generally adopted. Gmelin examined the ore in 1799 ‡; and his experiments coincide almost exactly with those of Muller and Klaproth. By these philosophers the following properties of tellurium have been ascertained.

Properties.

1. Its colour is bluish white, intermediate between that of zinc and lead; its texture is laminated like antimony; and its brilliancy is considerable.

2. Its hardness has not been ascertained. Its specific gravity, according to Klaproth, is 6.115 §.

3 It is very brittle, and may be easily reduced to powder.

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* Berg. ii. 468.

† Crell's *Annals*, 1798, i. 91.

‡ *Ibid.* 1799, i. 275. and 365.

§ Muller found it 6.343; but probably his specimen was not pure.

4. It melts when raised to a temperature somewhat higher than the fusing point of lead. If the heat be increased a little, it boils and evaporates, and attaches itself in brilliant drops to the upper part of the retort in which the experiment is made. It is therefore, next to mercury and arsenic, the most volatile of all the metals. When cooled slowly, it crystallizes.

Oxides.

II. When exposed to the action of the blow-pipe upon charcoal, it takes fire, and burns with a lively blue flame, the edges of which are green; and is completely volatilized in the form of a white smoke, which, according to Klaproth, has a smell not unlike that of radishes *.

This white smoke is the *oxide of tellurium*, which may be obtained also by dissolving the metal in nitro-muriatic acid, and diluting the solution with a great quantity of water. A white powder falls to the bottom, which is the oxide. It may be procured also by dissolving the metal in nitric acid, and adding potass slowly till the oxide precipitates. This oxide is easily melted by heat into a straw-coloured mass of a radiated texture. When made into a paste with oil, and heated in charcoal, it is reduced to the metallic state so rapidly, that a kind of explosion is produced.

Sulphuret.

III. Tellurium may be combined with sulphur by fusion. This sulphuret has a leaden grey colour, and a radiated texture: on red hot coals it burns with a blue flame.

Tellurium may be amalgamated with mercury by trituration. Its other properties have not yet been examined.

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* Gmelin could not perceive this smell

SECT. XIV.

OF ARSENIC.

History.

I. THE word *arsenic* (αρσενικον) occurs first in the works of Dioscorides, and of some other authors who wrote about the beginning of the Christian era. It denotes in their works the same substance which Aristotle had called σανδαραχη *, and his disciple Theophrastus αρρενικον, which is a reddish coloured mineral, composed of arsenic and sulphur, used by the ancients in painting, and as a medicine.

The *white oxide of arsenic*, or what is known in commerce by the name of arsenic, is mentioned by Avicenna in the 11th century; but at what period the metal called arsenic was first extracted from that oxide is unknown. Paracelsus seems to have known it; and a process for obtaining it is described by Schroeder in his Pharmacopœia published in 1649 †. But it was only in the year 1733 that this metal was examined with chemical precision. This examination, which was performed by Mr Brandt, demonstrated its peculiar nature; and since that time it has been always considered as a distinct metal, to which the term *arsenic* has been appropriated. Its properties were still farther investigated by Macquer in 1746 ‡, by Monnet in 1773 §, and

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* Pliny seems to make a distinction between sandaracha and arsenic. See lib. xxxiv. cap. 18.

† Bergman, ii. 278.

‡ *Mem. Par.* 1746, p. 223, and 1748, p. 35.

§ *Sur l'Arsenic.*

by Bergman in 1777[*]. To the labours of these philosophers, and to those of Mr Scheele[†], we are indebted for almost every thing known about the properties of this metal.

Properties.

1. Arsenic has a bluish white colour not unlike that of steel, and a good deal of brilliancy. It has no sensible smell while cold, but when heated it emits a strong odour of garlic, which is very characteristic.

2. Its hardness scarcely exceeds 5. Its specific gravity is 8.31[‡].

3. It is perhaps the most brittle of all the metals, falling to pieces under a very moderate blow of a hammer, and admitting of being easily reduced to a very fine powder in a mortar.

4. Its fusing point is not known, because it is the most volatile of the metals, subliming without melting when exposed in close vessels to a heat of 540°[§]. When sublimed slowly, it crystallizes in tetrahedrons, which Hauy has demonstrated to be the form of its integrant particles.

Oxides.

II. It may be kept under water without alteration; but when exposed to the open air, it soon loses its lustre, becomes black, and falls into powder.

Arsenic is capable of combining with two doses of oxygen, and of forming two compounds, which might be termed the *protoxide* and *peroxide* of arsenic, were it not that they possess several of the properties of acids.

Protoxide.

1. When exposed to a moderate heat in contact with

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[*] *Opusc.* ii. 272.

[†] Scheele, i. 129.

[‡] Bergman, ii. 254.

[§] Ibid.

air, it sublimes in the form of a white powder, and at the same time emits a smell resembling garlic. If the heat be increased, it burns with an obscure bluish flame. Arsenic indeed is one of the most combustible of the metals. The substance which sublimes was formerly called *arsenic* or *white arsenic*, and is still known by these names in the commercial world. It is a combination of arsenic and oxygen; and is now denominated *white oxide of arsenic*; and by Fourcroy *arsenious acid*, because it possesses several of the properties of an acid. It is seldom prepared by chemists, because it exists native; and is often procured abundantly during the extraction of the other metals from their ores.

When obtained by these processes, it is a white, brittle, compact substance, of a glassy appearance. It has a sharp acrid taste, which at last leaves an impression of sweetness, and is one of the most virulent poisons known. It has an alliacious smell. It is soluble in 80 parts of water at the temperature of 60°, and in 15 parts of boiling water*. This solution has an acrid taste, and reddens vegetable blues. When it is slowly evaporated, the oxide crystallizes in regular tetrahedrons. This oxide sublimes when heated to 283°: if heat be applied in close vessels, it becomes pellucid like glass; but when exposed to the air, it soon recovers its former appearance. The specific gravity of this glass is 5.000; that of the oxide, in its usual state, 3.706†. This oxide is capable of combining with most of the metals, and in general renders them brittle. From the

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* Bergman, ii. 291.

† Ibid. ii. 286.

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experiments of Proust, it appears that this oxide is composed of . . . . . 75.2 arsenic,
24.8 oxygen.

100.0*

Peroxide or arsenic acid.

2. Arsenic is capable of combining with an additional dose of oxygen, and of forming another compound, first discovered by Scheele, known by the name of *arsenic acid.* The process prescribed by Scheele is, to dissolve three parts of white oxide of arsenic in seven parts of muriatic acid, to add five parts of nitric acid, to put the mixture into a retort, and distil to dryness. The dry mass is to be merely brought to a red heat, and then cooled again. It is solid arsenic acid. Mr Bucholz has lately shewn, that the whole quantity of muriatic acid prescribed by Scheele is not necessary. The formula which he considers as the best is the following: Mix together in a crucible two parts of muriatic acid of the specific gravity 1.200, eight parts of white oxide of arsenic, and 24 parts of nitric acid, of the specific gravity 1.25. Evaporate to dryness, and expose the dry mass to a slight red heat †.

The acid thus prepared has no very strong taste when dry; but when dissolved in water, it acquires an excessively sour taste, and remains liquid even when evaporated to the consistence of a jelly. It is as noxious as the white oxide of arsenic. From the experiments of Proust, it follows that it is composed of 65.4 parts of arsenic, and 34.6 parts of oxygen: and with these proportions the determination of Bucholz very nearly corresponds.

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* *Jour. de Phys.*

† Van Mon's *Journal de Chimie*, iv. 16.

The remaining properties of these two combinations of arsenic and oxygen shall be described when we come to treat of the class of acids.

Union with combustibles.

III. 1. Arsenic does not combine with carbon nor hydrogen. This last substance, however, when in the gazeous state, dissolves it; for when muriatic acid is boiled over arsenic, that metal is gradually oxidized and dissolved, and at the same time hydrogen gas is emitted, which has the smell and the poisonous qualities of arsenic.

Sulphurets.

2. Sulphur combines readily with arsenic. If we put a mixure of these two bodies into a covered crucible and melt them, a red vitreous mass is obtained, which is obviously a sulphuret of arsenic. It may be formed also by heating together the white oxide of arſenic, or arsenic acid and sulphur. But in that case a portion of the sulphur absorbs the oxygen from the arsenic, and makes its escape in the form of sulphurous acid gas *. This sulphuret of arsenic is found native in different parts of Europe. It is usually called *realgar*. It has a scarlet colour, and is often crystallized in transparent prisms. Its specific gravity is 3.225 †. It is tasteless, and not nearly so hurtful as the oxides of arsenic, though Macquer affirms that it is poisonous. It is sometimes used as a paint. According to the experiments of Westrum, this sulphuret is composed of 80 parts of arsenic and 20 of sulphur ‡.

1. Realgar.

2. Orpiment.

3. If the white oxide of arsenic be dissolved in muriatic acid, and a solution of sulphureted hydrogen in water be poured into the liquid, a fine yellow-coloured

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* Proust, *Jour. de Phys.* liii. 94.

† Bergman, ii. 298.

‡ Crell's *Annals*, 1785. i. 299.

powder falls to the bottom. This powder is usually called orpiment. It may be formed by subliming arsenic and sulphur by a heat not sufficient to melt them. This substance is found native. It is composed of thin plates, which have a considerable degree of flexibility. Its specific gravity is 5·315. It has been supposed by some chemists that orpiment differs from realgar, merely in containing a smaller proportion of sulphur; by others, that the arsenic exists in it in the state of an oxide; by others, that it contains sulphureted hydrogen. But Mr Proust has ascertained, that when heated sufficiently it melts without emitting any gas, and on cooling assumes the appearance of realgar [*]. Hence we must conclude, that like realgar it is a sulphuret of arsenic, and that the two compounds differ merely in their state of aggregation; or perhaps the orpiment contains a small portion of water, which it loses by fusion. Mr Sage has observed, that if realgar be exposed to the light for some time, it assumes the yellow colour of orpiment [†].

Phosphuret.

4. Arsenic combines readily with phosphorus. The phosphuret of arsenic may be formed by distilling equal parts of its ingredients over a moderate fire. It is black and brilliant, and ought to be preserved in water. It may be formed likewise by putting equal parts of phosphorus and arsenic into a sufficient quantity of water, and keeping the mixture moderately hot for some time [‡].

IV. Arsenic does not combine with azotic gas nor

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[*] *Jour. de Phys.* liii. 94.

[†] Ibid. lvi. 55.

[‡] Pelletier, *Ann. de Chim.* xiii. 139.

muriatic acid; neither is it readily oxidized by the action of that acid.

Alloys with

V. Arsenic unites with most metals, and in general renders them more brittle and more fusible.

Gold,

1. Melted gold takes up $\frac{1}{60}$ of arsenic*. The alloy is brittle and pale, and much harder than gold.

Platinum,

2. The alloy of platinum and arsenic is brittle, and very fusible. It was first formed by Scheffer. The arsenic may be separated by heat. It is by fusing platinum and the white oxide of arsenic together that this untractable metal is formed into the utensils required. The mixture, after fusion, is hammered at a red heat into bars. The arsenic is gradually driven off, and carries along with it most of the baser metals which happen to be present. The platinum is then sufficiently ductile to be wrought.

Silver,

3. Melted silver takes up $\frac{1}{14}$ of arsenic†. The alloy is brittle, yellow-coloured, and useless.

Mercury,

4. Mercury may be amalgamated with arsenic by keeping them for some hours over the fire, constantly agitating the mixture. The amalgam is grey-coloured, and composed of five parts of mercury and one of arsenic‡.

Copper,

5. Copper may be combined with arsenic by fusing them together in a close crucible; while their surface is covered with common salt to prevent the action of the air, which would oxidize the arsenic. This alloy is white and brittle, and is used for a variety of purposes; but it is usual to add to it a little tin or bismuth.

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* Bergman, *Ann. de Chim.* xiii. 139

† Ibid.

‡ Bergman, ii. 281.

It is known by the names of *white copper* and *white tombac*. When the quantity of arsenic is small, the alloy is both ductile and malleable.

Iron, 6. Iron and arsenic may be alloyed by fusion. The alloy is white and brittle, and may be crystallized. It is found native; and is known among mineralogists by the name of *mispickel*. Iron is capable of combining with more than its own weight of arsenic [*].

Tin, 7. Tin and arsenic may be alloyed by fusion. The alloy is white, harder, and more sonorous than tin; and brittle, unless the proportion of arsenic be very small. An alloy, composed of 15 parts of tin and 1 of arsenic, crystallizes in large plates like bismuth: it is more brittle than zinc, and more infusible than tin. The arsenic may be separated by long exposure of the alloy to heat in the open air [†].

Lead, 8. Lead and arsenic may be combined by fusion. The alloy is brittle, dark-coloured, and composed of plates. Lead takes up $\frac{1}{6}$ of its weight of arsenic [‡].

Nickel, 9. Nickel combines readily with arsenic, and indeed is seldom found without being more or less contaminated by that metal. The compound has a shade of red, considerable hardness, and a specific gravity considerably under the mean. It is not magnetic. Arsenic possesses the curious property of destroying the magnetic virtue of iron, and all other metals susceptible of that virtue.

Zinc, 10. Zinc may be combined with arsenic by distilling a mixture of it and of white oxide of arsenic [§]. This

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[*] Bergman, ii. 281.

[†] Bayen.

[‡] Bergman.

[§] Malouin.

alloy, according to Bergman, is composed of four parts of zinc and one of arsenic.

Antimony,

11. Antimony forms with arsenic an alloy which is very brittle, very hard, and very fusible; and composed, according to Bergman, of seven parts of antimony and one part of arsenic.

Bismuth.

12. Bismuth may be combined with about $\frac{1}{15}$ of its weight of arsenic *; but the properties of this alloy have not been examined.

Affinities.

VI. The affinities of arsenic, and of its oxides, are placed by Bergman in the following order:

ARSENIC.	OXIDE OF ARSENIC.
Nickel,	Muriatic acid,
Cobalt,	Oxalic,
Copper,	Sulphuric,
Iron,	Nitric,
Silver,	Tartaric,
Tin,	Phosphoric,
Gold,	Fluoric,
Platinum,	Saclactic,
Zinc,	Succinic,
Antimony,	Citric,
Sulphur,	Lactic,
Phosphorus.	Arsenic,
	Acetic,
	Prussic.

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* Bergman, ii. 281.

Book I.
Division I.

SECT. XV.

OF COBALT.

History.

1. A MINERAL called *cobalt**, of a grey colour, and very heavy, has been used in different parts of Europe since the 15th century to tinge glass of a blue colour. But the nature of this mineral was altogether unknown till it was examined by Brandt in 1733. This celebrated Swedish chemist obtained from it a new metal, to

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* The word *cobalt* seems to be derived from *cobalus*, which was the name of a spirit that, according to the superstitious notions of the times, haunted mines, destroyed the labours of the miners, and often gave them a great deal of unnecessary trouble. The miners probably gave this name to the mineral out of joke, because it thwarted them as much as the supposed spirit, by exciting false hopes, and rendering their labour often fruitless; for as it was not known at first to what use the mineral could be applied, it was thrown aside as useless. It was once customary in Germany to introduce into the church-service a prayer that God would preserve miners and their works from *kobalts* and *spirits*. See Beckmann's *History of Inventions*, ii. 362.

Mathesius, in his tenth sermon, where he speaks of *cadmia fossilis* (probably cobalt ore), says, " Ye miners call it *cobolt*; the Germans call the black devil and the old devil's whores and hags, old and black *kobel*, which by their witchcraft do injury to people and to their cattle."

Lehmann, Paw, Delaval, and several other philosophers, have supposed that *smalt* (oxide of cobalt melted with glass and pounded) was known to the ancients, and used to tinge the beautiful blue glass still visible in some of their works; but we learn from Gmelin, who analysed some of these pieces of glass, that they owe their *blue* colour, not to the presence of *cobalt*, but of *iron*.

According to Lehmann, cobalt ore was first used to tinge glass blue by Christopher Schurer, a glassmaker at Platten, about the year 1540.

which he gave the name of *cobalt*[*]. Bergman confirmed and extended the discovery of Brandt in different dissertations published in the year 1780[†]. Scarcely any farther addition was made to our knowledge of this metal till 1798, when a paper on it was published by Mr Tassaert[‡]. In the year 1800, a new set of experiments were made upon it by the School of Mines at Paris, in order to procure it perfectly pure, and to ascertain its properties when in that state[§]. And in 1802, a new set of experiments were published by Thenard, which throw considerable light on its combinations with oxygen[||].

Properties.

1. Cobalt is of a grey colour with a shade of red, and by no means brilliant. Its texture varies according to the heat employed in fusing it. Sometimes it is composed of plates, sometimes of grains, and sometimes of small fibres adhering to each other[¶]. It has scarcely any taste or smell.

2. Its hardness is 6. Its specific gravity, according to Bergman and the School of Mines at Paris, is 7.7 ; but Tassaert makes it 8.5384.

3. It is brittle, and easily reduced to powder ; but if we believe Leonhardi, it is somewhat malleable when red hot. Its tenacity is unknown.

4. When heated to the temperature of 130° Wedgewood, it melts ; but no heat which we can produce is

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[*] *Acta Upsal*, 1733 and 1742.

[†] *Opusc.* ii. 444, 501. and iv. 371.

[‡] *Ann. de Chim.* xxviii. 101.

[§] Fourcroy, *Discours Preliminaire*, p. 114.

[||] *Ann. de Chim.* xlii. 210.

[¶] *L'Ecole des Mines.*

sufficient to cause it to evaporate. When cooled slowly in a crucible, if the vessel be inclined the moment the surface of the metal congeals, it may be obtained crystallized in irregular prisms *.

5. Like iron, it is attracted by the magnet; and, from the experiments of Wenzel, it appears that it may be converted into a magnet precisely similar in its properties to the common magnetic needle.

Oxides.

II. When exposed to the air it undergoes no change, neither is it altered when kept under water; its affinity for oxygen is not sufficiently strong to occasion a decomposition of the water.

When kept red hot in an open vessel, it gradually imbibes oxygen, and is converted into a powder at first blue, but which gradually becomes deeper and deeper, till at last it becomes black, or rather of so deep a blue that it appears to the eye black. If the heat be very violent, the cobalt takes fire and burns with a red flame.

From the experiments of Thenard, it follows that cobalt is capable of combining with three doses of oxygen at least, and of forming three distinct oxides, which may be exhibited in a separate state.

Protoxide.

1. The protoxide of cobalt has a blue colour. It may be obtained by dissolving cobalt in nitric acid, and precipitating the cobalt from the solution by means of potass. The precipitate has a blue colour, but when dried in the open air it gradually becomes black. This black powder is to be kept for half an hour in that degree of heat known to manufacturers of iron utensils by

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* Fourcroy, v. 137.

the name of *cherry red*. This heat expels the oxygen which it had absorbed in drying, and converts it into a fine blue colour. This oxide dissolves in acids without effervescence. The solution of it in muriatic acid, if concentrated, is green; but if diluted with water, it is red. Its solution in sulphuric and nitric acids is always of a red colour [*].

Deutoxide.

2. When the protoxide of cobalt, newly precipitated from acids by potass, is exposed to the air, it gradually combines with an additional dose of oxygen, as Thenard ascertained by experiment, and assumes an olive green colour; and by cautiously drying it without the aid of heat, it may be obtained in that state. This is the *deutoxide* of cobalt. When this oxide is treated with diluted muriatic acid, a moderate heat developes oxymuriatic acid gas, and a red coloured solution is obtained. Hence we see that the deutoxide of cobalt loses a portion of its oxygen during its solution in muriatic acid [†].

Peroxide.

3. When the protoxide or deutoxide of cobalt, newly precipitated from an acid, is dried by heating it in the open air, it assumes a flea-brown colour, which gradually deepens till at last it becomes black. This is the peroxide of cobalt. It dissolves with effervescence in muriatic acid, and a great quantity of oxymuriatic acid gas is exhaled. Mr Thenard considers the brown colour which the oxide of cobalt first assumes before it becomes black as a *tritoxide*; but his experiments are not sufficient to decide that point.

With respect to the reddish precipitate which is

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[*] *Ann. de Chim.* xlii. 213.

[†] *Ibid.* 2 2.

sometimes obtained by precipitating cobalt from acids, and which has been considered as a peculiar oxide of cobalt, Mr Thenard suspects, with reason, that it is a combination of the oxide of cobalt with arsenic acid*.

Union with combustibles.

III. 1. Cobalt does not combine with carbon nor hydrogen.

Sulphuret.

2. It cannot be combined with sulphur by fusion. But sulphuret of cobalt may be formed by melting the metal along with sulphur previously combined with potass. It has a yellowish white colour, displays the rudiments of crystals, and can scarcely be decomposed by heat.

Phosphuret.

3. Phosphuret of cobalt may be formed by heating the metal red hot, and then gradually dropping in small bits of phosphorus. It contains about $\frac{1}{15}$th of phosphorus. It is white and brittle; and when exposed to the air, soon loses its metallic lustre. The phosphorus is separated by heat, and the cobalt is at the same time oxidated. This phosphuret is much more fusible than pure cobalt †.

IV. Cobalt does not combine with azotic gas nor muriatic acid gas.

Alloys with

V. Cobalt seems capable of combining with most of the metals, but its alloys are very imperfectly known.

Gold,

1. Cobalt combines with a small portion of gold; but the alloy scarcely differs from pure cobalt in its properties.

2. The alloy of cobalt and platinum has not been examined.

Silver,

3. When 2 parts of cobalt and 1 of silver are melted

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* *Ann. de Chim.* xlii. 214.

† Pelletier, *Ibid.* xiii. 134.

together, the two metals are obtained separately after the process; the silver at the bottom of the crucible, and the cobalt above it. Each of them, however, has absorbed a small portion of the other metal: for the silver is brittle and dark coloured, while the cobalt is whiter than usual *.

4. Cobalt does not combine with mercury.

5. The alloy of copper and cobalt is scarcely known.

Iron,

6. The alloy of iron and cobalt is very hard, and not easily broken. Cobalt generally contains some iron, from which it is with great difficulty separated.

Tin,

7. The alloy of tin and cobalt is of a light violet colour, and formed of small grains.

Lead,

8. It was supposed formerly that cobalt does not combine with lead by fusion; for upon melting equal parts of lead and cobalt together, both metals are found separate, the lead at the bottom and the cobalt above. Indeed when this cobalt is melted with iron, it appears that it had combined with a little lead; for the iron combines with the cobalt, and the lead is separated †. But Gmelin has shown that the alloy may be formed. He put cobalt in powder within plates of lead, and covered them with charcoal to exclude the air. He then applied heat to the crucibles containing the mixtures. Equal parts of lead and cobalt produced an alloy, in which the metals appeared pretty uniformly distributed, though in some places the lead predominated. It was brittle, received a better polish than lead, which metal it resembled rather than cobalt; its specific gravity was 8.12. Two part of lead and one of cobalt produced an

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* Gellert, p. 137.

† Ibid.

uniform mixture, more like cobalt than lead, very little malleable, and softer than the last. Its specific gravity was 8.28. Four parts of lead and one of cobalt formed an alloy still brittle, and having the fracture of cobalt, but the polish of lead. It was harder than lead. Six parts of lead and one of cobalt formed an alloy more malleable, and harder than lead. Its specific gravity was 9.65. Eight parts of lead and one of cobalt was still harder than lead, and it received a better polish. It was as malleable as lead. Its specific gravity was 9.78*.

Nickel, 9. Cobalt is often found naturally combined with nickel.

10. It does not seem capable of combining with bismuth nor with zinc by fusion.

Affinities. VI. The affinities of cobalt, and its oxides, are, according to Bergman, as follows:

COBALT.	OXIDE OF COBALT.
Iron,	Oxalic acid,
Nickel,	Muriatic,
Arsenic,	Sulphuric,
Copper,	Tartaric,
Gold,	Nitric,
Platinum,	Phosphoric,
Tin,	Fluoric,
Antimony,	Saclactic,
Zinc,	Succinic,
Phosphorus,	Citric,
Sulphur.	Lactic,

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* *Ann. de Chim.* xix. 357.

Acetic,
Arsenic,
Boracic,
Prussic,
Carbonic.

SECT. XVI.

OF MANGANESE.

History.

1. THE dark grey or brown mineral called *manganese*, in Latin *magnesia* (according to Boyle, from its resemblance to the *magnet*), has been long known and used in the manufacture of glass. A mine of it was discovered in England by Boyle. A few experiments were made upon this mineral by Glauber in 1656 [*], and by Waitz in 1705 [†]; but chemists in general seem to have paid but very little attention to it. The greater number of mineralogists, though much puzzled what to make of it, agreed in placing it among iron ores: but Pott, who published the first chemical examination of this mineral in 1740, having ascertained that it often contains scarcely any iron, Cronstedt, in his *System of Mineralogy*, which appeared in 1758, assigned it a place of its own, on the supposition that it consisted chiefly of a peculiar earth. Rinman examined it anew in 1765 [‡]; and in the year 1770 Kaim published at Vienna a set of experiments, in order to prove that a peculiar metal might be extracted from it [§]. The same idea had struck

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[*] *Prosperitas Germaniæ.*

[†] Wieglcb's *Geschichte*, i. 127.

[‡] *Mem. Stockholm*, 1765, p. 235.

[§] *De Metallis dubiis*, p. 48.

Bergman about the same time, and induced him to request of Scheele, in 1771, to undertake an examination of manganese. Scheele's dissertation on it, which appeared in 1774, is a masterpiece of analysis, and contains some of the most important discoveries of modern chemistry. Bergman himself published a dissertation on it the same year; in which he demonstrates, that the mineral, then called *manganese*, is a metallic oxide *. He accordingly made several attempts to reduce it, but without success; the whole mass either assuming the form of scoriæ, or yielding only small separate globules attracted by the magnet. This difficulty of fusion led him to suspect that the metal he was in quest of bore a strong analogy to platinum. In the mean time, Dr Gahn, who was making experiments on the same mineral, actually succeeded in reducing it by the following process: He lined a crucible with charcoal powder moistened with water, put into it some of the mineral formed into a ball by means of oil, then filled up the crucible with charcoal powder, luted another crucible over it, and exposed the whole for about an hour to a very intense heat. At the bottom of the crucible was found a metallic button, or rather a number of small metallic globules, equal in weight to one-third of the mineral employed †. It is easy to see by what means this reduction was accomplished. The charcoal attracted the oxygen from the oxide, and the metal remained behind. The metal obtained, which is called *manganese*, was farther examined by Ilseman in 1782, Hielm in 1785, and Bindheim in 1789.

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* *Opusc.* ii. 201.

† Bergman, ii. 211.

Properties.

1. Manganese, when pure, is of a greyish-white colour, and has a good deal of brilliancy. Its texture is granular. It has neither taste nor smell.

2. Its hardness is 9, or equal to that of iron. Its specific gravity is 7.000 *.

3. It is very brittle; of course it can neither be hammered nor drawn out into wire. Its tenacity is unknown.

4. It requires, according to Morveau, the temperature of 160° Wedgewood to melt it; so that, platinum excepted, it is the most infusible of all the metals.

5. When reduced to powder, it is attracted by the magnet, owing probably to a small portion of iron from which it can with difficulty be parted.

Oxides.

II. Manganese, when exposed to the air, attracts oxygen more rapidly than any other body, phosphorus excepted. It loses its lustre almost instantly, becomes grey, violet, brown, and at last black. These changes take place still more rapidly if the metal be heated in an open vessel.

This metal seems capable of combining with three different proportions of oxygen, and of forming three different oxides, the *white*, the *red*, and the *black*.

Protoxide.

1. The protoxide or white oxide may be obtained by dissolving the black oxide of manganese in nitric acid by adding a little sugar. The sugar attracts oxygen from the black oxide, and converts it into the white, which is dissolved by the acid. Into the solution pour a quantity of potass; the protoxide precipitates in the form of a white powder. It is composed, according to Bergman, of 80 parts of manganese and 20 of oxygen.

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* Hielm.

When exposed to the air, it soon attracts oxygen, and is converted into the black oxide *.

Deutoxide.

2. The deutoxide or *red* oxide may be obtained by dissolving the black oxide in sulphuric acid, without the addition of any combustible substance. When black oxide of manganese, made into a paste with sulphuric acid, is heated in a retort, a great quantity of oxygen gas comes over, while the oxide, thus deprived of part of its oxygen, dissolves in the acid. Distil to dryness, and pour water upon the residuum, and pass it through a filter. A red coloured solution is obtained, consisting of the sulphat of manganese dissolved in the water. On the addition of an alkali, a red substance precipitates, which is the *red oxide of manganese*. According to Bergman, it is composed of 74 parts of manganese and 26 of oxygen †. This oxide likewise attracts oxygen when exposed to the atmosphere, and is converted into the black oxide.

Peroxide.

3. The peroxide or *black* oxide of manganese exists abundantly in nature; indeed it is almost always in this state that manganese is found. It was to the black oxide that the appellation *manganese* itself was originally applied. It may be formed very soon by exposing the metal to the air. This oxide, according to Fourcroy, is composed of 60 parts of manganese and 40 of oxygen ‡. When heated to redness in an earthen retort, it gives out abundance of oxygen gas, which may be collected in proper vessels. By this operation it is reduced nearly to the state of red oxide. If it be exposed to the air, and moistened occasionally, it absorbs a new dose of oxygen; and thus the same process

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* *Opusc.* ii. 211.

† Ibid. ii. 215.

‡ Fourcroy, v. 177.

may again be repeated *. No oxygen gas can be obtained from the white oxide : a proof that its oxygen is retained by a stronger affinity than the additional dose of oxygen which constitutes the black oxide Seguin has observed, that in some cases the black oxide of manganese emits, before it becomes red, a quantity of azotic gas †. When long exposed to a strong heat, it assumes a green colour. In that state it is whitened by sulphuric acid, but not dissolved ‡. A very violent heat fuses this oxide, and converts it into a green coloured glass.

Union wit combusti bles.

III. 1. Manganese does not combine with hydrogen. When dissolved in sulphuric acid, a black spongy mass of carburet of iron is left behind. Hence it has been supposed capable of combining with carbon; but it is more probable that the carbon is combined with the iron, which is almost always present in manganese. It seems pretty clear, however, that carburet of iron is capable of combining with this metal, and that it always forms a part of steel.

Sulphuret.

2. Bergman did not succeed in his attempt to combine manganese with sulphur ; but he formed a sulphureted oxide of manganese, by combining eight parts of the black oxide with three parts of sulphur. It is of a green colour, and gives out sulphureted hydrogen gas

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* It may be necessary to mention, that with me this absorption has succeeded but imperfectly, unless when the red or white oxides of manganese have been precipitated from an acid.

† Owing most likely to the filtration of air through the earthen ware retort, in which the manganese was heated. I have never observed any azotic gas when manganese is heated in an iron bottle.

‡ Bergman, ii. 216.

when acted on by acids *. It cannot be doubted, however, that sulphur is capable of combining with manganese; for Proust has found native sulphuret of manganese in that ore of tellurium which is known by the name of gold ore of Nagyag †.

Phosphuret.

3. Phosphorus may be combined with manganese by melting together equal parts of the metal and of phosphoric glass; or by dropping phosphorus upon red hot manganese. The phosphuret of manganese is of a white colour, brittle, granulated, disposed to crystallize, not altered by exposure to the air, and more fusible than manganese. When heated the phosphorus burns, and the metal is oxidized ‡.

IV. Manganese does not combine with either of the simple incombustibles.

Alloys.

V. Manganese combines with many of the metals, and forms with them alloys which have been but very imperfectly examined.

It unites readily with copper. The compound, according to Bergman, is very malleable, its colour is red, and it sometimes becomes green by age. Gmelin made a number of experiments to see whether this alloy could be formed by fusing the black oxide of manganese along with copper. He partly succeeded, and proposed to substitute this alloy instead of the alloy of copper and arsenic, which is used in the arts ¶.

It combines readily with iron; indeed it has scarcely ever been found quite free from some mixture of that metal. Manganese gives iron a white colour, and ren-

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* Bergman, p. 221.

† *Jour. de Phys.* lvi. 1.

‡ Pelletier, *Ann. de Chim.* xiii. 137.

¶ *Ann. de Chim.* i. 303.

ders it brittle. It combines also with tin, but scarcely with zinc *.

It does not combine with mercury nor with bismuth. Gmelin found that manganese cannot be alloyed with bismuth without great difficulty; and that it unites to antimony very imperfectly †. Chemists have not attempted to combine it with gold, platinum, silver, nickel, nor cobalt.

Affinities.

VI. The affinities of manganese, and of its white and red oxides, are, according to Bergman, as follows:

MANGANESE.	OXIDE OF MANGANESE.
Copper,	Oxalic acid,
Iron,	Citric,
Gold,	Phosphoric,
Silver,	Tartaric,
Tin.	Fluoric,
	Muriatic,
	Sulphuric,
	Nitric,
	Saclactic,
	Succinic,
	Tartaric,
	Lactic,
	Acetic,
	Prussic,
	Carbonic.

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[*] Bergman, ii. p. 205.

[†] *Ann. de Chim.* xix 366.

Book I. Division I.

SECT. XVII.

OF TUNGSTEN.

History.

I. THERE is a mineral found in Sweden of an opaque white colour and great weight; from which last circumstance it got the name of *tungsten*, or *ponderous stone*. Some mineralogists considered it as an ore of tin, others supposed that it contained iron. Scheele analysed it in 1781, and found that it was composed of lime and a peculiar earthy-like substance, which he called from its properties *tungstic acid* *. Bergman conjectured that the basis of this acid is a metal †; and this conjecture was soon after fully confirmed by the experiments of Messrs D'Elhuyart, who obtained the same substance from a mineral of a brownish black colour, called by the Germans *wolfram* ‡, which is sometimes found in tin mines. This mineral they found to contain $\frac{65}{100}$ of tungstic acid; the rest of it consisted of manganese, iron, and tin. This acid substance they mixed with charcoal powder, and heated violently in a crucible. On opening the crucible after it had cooled, they found in it a button of metal, of a dark brown colour, which crumbled to powder between the fingers. On viewing it with a glass, they found it to consist of a congeries of metallic globules, some of which were as

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* Scheele, ii. 81.

† Ibid. ii. 91.

‡ Wolfram had been analysed in 1761 by Lehmann. He imagined it a compound of iron and tin. See his *Probierkunst*, p. 8.

large as a pin head. The metal thus obtained is called *tungsten*. The manner in which it was produced is evident: tungstic acid is composed of oxygen and tungsten; the oxygen combined with the carbon, and left the metal in a state of purity [*].

The experiments of the Elhuyarts were repeated in 1796 by Vauquelin and Hecht, in general with success; but they were unable to procure the metal completely fused, though this had been accomplished by the Spanish chemists [†]. Nor is this to be wondered at, as Dr Pearson [‡] and Mr Klaproth [§] had made the same attempt before them without succeeding. The fusion of this metal is said to have been lately accomplished by Messrs Allen and Aiken of London. They succeeded by applying a strong heat to the combination of the oxide of tungsten and ammonia [||].

Properties.

1. Tungsten, called by some of the German chemists *scheelium*, is of a greyish-white colour, or rather like that of iron, and has a good deal of brilliancy.

2. It is one of the hardest of the metals; for Vauquelin and Hecht could scarcely make any impression upon it with a file. It seems also to be brittle. Its specific gravity, according to the D'Elhuyarts, is 17.6; according to Allen and Aiken, 17 22 [¶]. It is therefore the heaviest of the metals after gold and platinum.

2. It requires for fusion a temperature at least equal

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[*] *Mem. Thoulouse*, ii. 141. This memoir has been translated into English.

[†] *Jour. de Min.* No. xix. 3.

[‡] *Transl. of the Chem. Nomenclature.*

[§] *Observ. on the Fossils of Cornwall*, p. 77.

[||] *Jour. de Chim.* iii. 115.

[¶] Ibid

to 170° Wedgewood. It seems to have the property of crystallizing on cooling, like all the other metals; for the imperfect button procured by Vauquelin and Hecht contained a great number of small crystals.

3. It is not attracted by the magnet.

Oxides.

II. When heated in an open vessel, it gradually absorbs oxygen, and is converted into an oxide. Tungsten seems capable of combining with two different proportions of oxygen, and of forming two different oxides; the *black* and the *yellow*.

Protoxide.

1. The protoxide or black oxide, may be obtained by heating the yellow oxide for some hours in a covered crucible.

Peroxide.

2. The peroxide or yellow oxide, known also by the name of *tungstic acid* *, is found native in Wolfram, and may be obtained from it by boiling three parts of muriatic acid on one part of wolfram. The acid is to be decanted off in about half an hour, and allowed to settle. A yellow powder gradually precipitates. This powder is to be dissolved in *ammonia* †, the solution is to be evaporated to dryness, and the dry mass kept for some time in a red heat. It is then *yellow oxide* in a state of purity ‡. This oxide has no taste. It is inso-

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* The tungstic acid of Scheele is different from this oxide. It is a white powder of an acid taste, and soluble in water. The D'Elhuyarts have demonstrated that it is a triple salt, composed of the yellow oxide of tungsten, potass, and the acid employed to decompose the mineral from which it is obtained.

† An alkali which will be afterwards described.

‡ A more economical process for procuring this oxide has been proposed by Bucholz. His formula is as follows: Mix one part of wolfram in fine powder with two parts of *subcarbonat of potass*, keep the mixture

luble in water, but remains long suspended in that liquid, forming a kind of yellow milk, which has no action on vegetable colours. When heated in a platinum spoon it becomes dark green; but before the blow-pipe on charcoal it acquires a black colour. It is composed of 80 parts of tungsten and 20 of oxygen. Its specific gravity is 6.12.

Union with combustibles.

III. 1. The sulphuret of tungsten is of bluish black colour, hard, and capable of crystallizing.

2. Phosphorus is capable of combining with tungsten *; but none of the properties of the phosphuret have been ascertained.

IV. The simple incombustibles do not seem capable of uniting with tungsten.

Alloys.

V. The Elhuyarts alone attempted to combine tungsten with other metals. They mixed 100 grains of the metals to be alloyed with 50 grains of the yellow oxide of tungsten and a quantity of charcoal, and heated the mixture in a crucible. The result of their experiments is as follows:

Experiments of the Elhuyarts.

1. With gold and platinum the tungsten did not combine.

2. With silver it formed a button of a whitish-brown colour, something spongy, which with a few strokes

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melted in a crucible for an hour, stirring it occasionally. Then pour it into an iron cone. Before the mass be quite cold, reduce it to powder, and boil water on it repeatedly till the liquid comes off tasteless. Mix all the watry solutions together, and pour muriatic acid into them as long as any precipitate appears. Wash the precipitate; dissolve it in boiling carbonat of potass, precipitate again by muriatic acid, wash the precipitate, and dry it upon filtering paper. It is pure peroxide of tungsten. See *Jour. de Chim.* iii. 220.

* Pelletier, *Ann. de Chim.* xiii. 137.

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of a hammer extended itself easily, but on continuing them it split in pieces. This button weighed 142 grains.

3. With copper it gave a button of a copperish red, which approached to a dark brown, was spongy, and pretty ductile, and weighed 133 grains.

4. With crude or cast iron, of a white quality, it gave a perfect button, the fracture of which was compact and of a whitish brown colour: it was hard, harsh, and weighed 137 grains.

5. With lead it formed a button of a dull dark brown, with very little lustre, spongy, very ductile, and splitting into leaves when hammered: it weighed 127 grains.

6. The button formed with tin was of a lighter brown than the last, very spongy, somewhat ductile, and weighed 138 grains.

7. That with antimony was of a dark-brown colour, shining, something spongy, harsh, and broke in pieces easily: it weighed 108 grains.

8. That of bismuth presented a fracture, which, when seen in one light, was of a dark brown colour, with the lustre of a metal, and in another appeared like earth, without any lustre; but in both cases one could distinguish an infinity of little holes over the whole mass. This button was pretty hard, harsh, and weighed 68 grains.

9. With manganese it gave a button of a dark bluish-brown colour and earthy aspect; and, on examining the internal part of it with a lens, it resembled impure dross of iron: it weighed 107 grains.

SECT. XVIII.

OF MOLYBDENUM.

History.

I. THE Greek word μολυβδαινα, and its Latin translation *plumbago*, seem to have been employed by the ancients to denote various oxides of lead; but by the moderns they were applied indiscriminately to all substances possessed of the following properties: Light, friable, and soft, of a dark colour and greasy feel, and which leave a stain upon the fingers. Scheele first examined these minerals with attention. He found that two very different substances had been confounded together. To one of these, which is composed of carbon and iron, and which has been already described, he appropriated the word *plumbago*; the other he called *molybdena*.

Molybdena is composed of scaly particles adhering slightly to each other. Its colour is bluish, very much resembling that of lead. Scheele analysed it in 1778, and obtained sulphur and a whitish powder, which possessed the properties of an acid, and which, therefore, he called *acid of molybdena* [*]. Bergman suspected this acid, from its properties, to be a metallic oxide; and at his request, Hielm, in 1782, undertook the laborious course of experiments by which he succeeded in obtaining a metal from this acid. His method was to form it into a paste with linseed oil, and then to apply a very strong heat. This process he repeated several times successively [†]. To the metal which he obtained he

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[*] Scheele, i. 236.

[†] Bergman's *Sciagraphia*, p. 19. Engl. Transl.

gave the name of *molybdenum* *. The experiments of Scheele were afterwards repeated by Pelletier †, Ilseman ‡, and Heyer §; and not only fully confirmed, but many new facts discovered, and the metallic nature of molybdic acid was put beyond a doubt: though, in consequence of the very violent heat necessary to fuse molybdenum, only very minute grains of it have been hitherto obtained in the state of a metal. Still more lately Mr Hatchett has published a very valuable set of experiments, which throw much new light upon the nature of this metal ¶.

Properties.

1. Molybdenum is externally of a whitish yellow colour, but its fracture is a whitish grey.

2. Hitherto it has only been procured in small grains, agglutinated together in brittle masses.

3. Its specific gravity is 7.500. It is almost infusible in our fires.

Oxides.

II. When exposed to heat in an open vessel, it gradually combines with oxygen, and is converted into a white oxide, which is volatilized in small brilliant needleform crystals. This oxide, having the properties of an acid, is known by the name of *molybdic acid.*

From the experiments of Mr Hatchet, it follows that molybdenum is capable of combining with four different proportions of oxygen, and of forming four oxides; namely, 1. The black; 2. The blue; 3. The green, to which Mr Hatchett has given the name of *molybdous acid;* and, 4. The *yellow* or *white,* or the molybdic acid ||.

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* Crell's *Annals*, 1790, i. 39, &c.

† *Jour. de Phys.* 1785, Decembre.

‡ Crell's *Annals*, 1787, i. 407.

§ Ibid. 1787. ii. 21. and 124.

¶ *Phil. Trans.* 1795, p. 323.

|| Ibid. p. 323.

Protoxide.

1. The protoxide or black oxide may be obtained by mixing molybdic acid with charcoal powder in a crucible, and applying heat. A black mass remains, which is the black oxide. It seems to contain only a very minute quantity of oxygen.

Deutoxide.

2. The blue oxide may be obtained by the same process not carried so far: it is formed also whenever a plate of tin is plunged into a solution of molybdic acid.

Peroxide.

3. The peroxide, or molybdic acid, is obtained by distilling six parts of diluted nitric acid repeatedly off native molybdena in powder. A white mass is left behind, composed of sulphuric and molybdic acids. A little pure water washes away the sulphuric acid, and molybdic acid remains behind. This acid has at first a white colour; but when melted and sublimed, it becomes yellow.

Union with combustibles.

III. 1. Molybdenum combines readily with sulphur; and the compound has exactly the properties of molybdena, the substance which Scheele decompounded *. Molybdena is therefore *sulphuret of molybdenum.* The reason that Scheele obtained from it molybdic acid was, that the metal combined with oxygen during his process. Sulphuret of molybdenum may be formed also by distilling together one part of molybdic acid and five parts of sulphur.

2. Molybdenum is also capable of combining with phosphorus †.

Alloys.

IV. Few of the alloys of this metal have been hitherto examined.

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* Pelletier, *Jour. de Phys.* 1785.

† Pelletier, *Ann. de Chim.* xiii. 137.

It seems capable of uniting with gold. The alloy is probably of a white colour [*].

It combines readily with platinum while in the state of an oxide. The compound is fusible. Its specific gravity is 20.000 [†].

The alloys of molybdenum with silver, iron, and copper, are metallic and friable ; those with lead and tin are powders which cannot be fused [‡]. Several other combinations have been made both by Hielm and Richter ; but as the metals which they tried were alloyed not with molybdenum, but with molybdic acid, they cannot be considered as by any means the same with the alloys formed by molybdenum itself.

SECT. XIX.

OF URANIUM.

History.

I. THERE is a mineral found in the George Wagsfort mine at Johnann-Georganstadt in Saxony, partly in a pure or unmixed state, and partly stratified with other kinds of stones and earths. The first variety is of a blackish colour inclining to a dark iron grey, of a moderate splendor, a close texture, and when broken presents a somewhat even, and, in the smallest particles, a conchoidal surface. It is quite opaque, tolerably hard, and on being pounded yields a black powder. Its specific gravity is about 7.500. The second sort is di-

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[*] Ruprecht, *Ann. de Chim.* viii. 8. [†] Hielm, *Ann. de Chim.* iv. 17.
[‡] Pelletier, *Jour. de Phys.* Dec. 1785.

stinguished by a finer black colour, with here and there a reddish cast; by a stronger lustre, not unlike that of pitcoal; by an inferior hardness; and by a shade of green, which tinges its black colour when it is reduced to powder [*].

This fossil was called *pechblende*; and mineralogists, misled by the name [†], had taken it for an ore of zinc, till the celebrated Werner, the father of mineralogy, convinced from its texture, hardness, and specific gravity, that it was not a *blende*, placed it among the ores of iron. Afterwards he suspected that it contained *tungsten*; and this conjecture was seemingly confirmed by the experiments of some German mineralogists, published in the Miners Journal [‡]. But Klaproth, the most celebrated analyst in Europe, examined this ore in 1789, and found that it consists chiefly of sulphur combined with a peculiar metal, to which he gave the name of *uranium* [||].

Properties.

Uranium is of a dark grey colour; internally it is somewhat inclined to brown [§].

Its malleability is unknown. Its hardness is about 6. It requires a stronger heat for fusion than manganese. Indeed Klaproth only obtained it in very small conglutinated metallic grains, forming altogether a porous and spongy mass. Its specific gravity is 6.440 [¶].

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[*] Klaproth, Crell's *Journal*, Eng. Transl. i. 126.

[†] *Blende* is the name given to ores of zinc.

[‡] Ibid.

[||] From *Uranus* (Ουρανος), the name given by Mr Bode to the new planet discovered by Herschel; which name the German astronomers have adopted. Mr Klaproth called the metal at first *uranite*; but he afterwards changed that name for *uranium*.

[§] Ibid. 233.

[¶] Ibid.

Oxides.

II. When exposed for some time to a red heat, it suffers no change. By means of nitric acid, however, it may be converted into a yellow powder. This is the peroxide or *yellow oxide of uranium*, which seems to be composed of about 56 parts of uranium and 44 of oxygen. This oxide is found native mixed with the mineral above described. From the experiments of Proust, we learn, that this metal is capable of forming only two oxides, but no description of the protoxide has been published ; and the ore is so scarce that it is not every chemist who can gratify his curiosity by an examination of uranium *.

Sulphuret.

III. Uranium is capable of combining with sulphur. The mineral from which Mr Klaproth first obtained it is a native sulphuret of uranium.

Nothing is known concerning the alloys or affinities of uranium.

SECT. XX.

OF TITANIUM.

History.

I. In the valley of Menachan, in Cornwall, there is found a black sand, bearing a strong resemblance to gunpowder. It was examined in 1781 by Mr Gregor, who found it composed almost entirely of iron, and the oxide of a new metal, to which he gave the name of

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[*] Mr Proust at first mistook uranium for a new metal, and gave it the name of *silenum*. But he very soon rectified this mistake. See *Jour. de Phys.* lvi. p. 467.

menachine *. He attempted in vain to reduce this oxide to the metallic state; but his experiments were sufficient to demonstrate the metallic nature of the substance, and to shew that it contained a metal till then absolutely unknown. This curious and ingenious analysis seems to have excited but little attention, since nobody thought of repeating it, or of verifying the conclusions of Mr Gregor.

But in 1795 Klaproth published the analysis of a brownish red mineral, known to mineralogists by the name of *red shorl.* He found it entirely composed of the oxide of a peculiar metal, to which he gave the name of *titanium* †. He failed indeed in his attempts to reduce this oxide, but his experiments left no doubt of its metallic nature. On examining in 1797 the black mineral analysed by Mr Gregor, he found it a compound of the oxides of iron and titanium ‡. Consequently the analysis of Mr Gregor was accurate, and his *menachine* is the same with *titanium*, of which he was undoubtedly the original discoverer. The term *titanium* has been preferred by chemists, on account of the great celebrity and authority of the illustrious philosopher who imposed it. Klaproth's experiments were repeated, confirmed, and extended by Vauquelin and Hecht in 1796, who succeeded in reducing a very minute portion of the oxide of titanium to the metallic state §. They were repeated also and confirmed by Lowitz of Petersburgh in 1798 ¶. By these philoso-

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* *Jour. de Phys.* xxxix. 72. and 152.

† Beitrage, i. 233.

‡ Ibid. ii. 226.

§ *Jour. de Min.* No. xv. 10

¶ Crell's *Annals*, 1799. i. 183.

phers the following properties of titanium have been ascertained.

Properties.

1. Its colour is orange-red, and it has a good deal of lustre.

2. As it has been only obtained in very small agglutinated grains, neither its hardness, specific gravity, nor malleability, have been ascertained.

3. It is one of the most infusible of metals, requiring a greater heat to melt it than can be produced by any method at present known.

Oxides.

II. When heated in the open air, it combines readily with oxygen, and seems capable of forming three different oxides; namely, the *blue* or *purple*, the *red*, and the *white*.

Protoxide.

1. The protoxide, which is of a blue or purple colour, is formed, when titanium is exposed hot to the open air, evidently in consequence of the absorption of oxygen.

Deutoxide.

2 The deutoxide or red oxide is found native. It is often crystallized in four-sided prisms; its specific gravity is about 4.2; and it is hard enough to scratch glass. When heated it becomes brown, and when urged by a very violent fire some of it is volatilized. When heated sufficiently along with charcoal, it is reduced to the metallic state.

Peroxide.

3. The peroxide or white oxide may be obtained by fusing the red oxide in a crucible with four times its weight of potass, and dissolving the whole in water. A white powder soon precipitates, which is the white oxide of titanium. Vauquelin and Hecht have shown that it is composed of 89 parts of red oxide and 11 parts of oxygen.

Union with combustibles.

III. 1. Titanium does not seem to be capable of combining with sulphur [*].

2. Phosphuret of titanium has been formed by Mr Chenevix by the following process: He put a mixture of charcoal, phosphat of titanium (phosphoric acid combined with oxide of titanium), and a little borax, into a double crucible, well luted, and exposed it to the heat of a forge. A gentle heat was first applied, which was gradually raised for three quarters of an hour, and maintained for half an hour as high as possible. The phosphuret of titanium was found in the crucible in the form of a metallic button. It is of a pale white colour, brittle, and granular; and does not melt before the blowpipe [†].

Alloys.

IV. Vauquelin and Hecht attempted to combine it with silver, copper, lead, and arsenic, but without success. But they combined it with iron, and formed an alloy of a grey colour, interspersed with yellow coloured brilliant particles. This alloy they were not able to fuse.

Affinities.

V. The affinities of the oxides of titanium are, according to Professor Lampadius, as follows [‡]:

Gallic acid,
Phosphoric,
Arsenic,
Oxalic,
Sulphuric,
Muriatic,
Nitric,
Acetic.

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[*] Gregor.

[†] Nicholson's *Journal*, v. 134.

[‡] *Ann. de Chim.* xxvi. 91.

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SECT. XXI.

OF CHROMIUM.

History.

I. In the year 1766, Lehmann, in a letter to Buffon, published the first description of a beautiful red mineral with a shade of yellow, crystallized in four-sided prisms, which is found in the mine of Beresof, near Ekaterimbourg in Siberia. This mineral, known by the name of *red lead ore of Siberia*, was used as a paint, and is now become exceedingly scarce and dear. It was examined soon after by Pallas, who considered it as a compound of lead, arsenic, and sulphur. Macquart, who in 1783 was sent upon a mineralogical expedition to the north of Europe, having brought a quantity of it to Paris, analysed it in 1789 in company with Mr Vauquelin. These gentlemen concluded, from their analysis, that it is a compound of the oxides of lead and of iron. On the other hand, Mr Bindheim of Moscow concluded, from an analysis of his own, that its ingredients are lead, molybdic acid, and nickel. These discordant analyses destroyed each other, and prevented mineralogists from putting any confidence in either. This induced Vauquelin, who had now made himself a consummate master of the art of analysing minerals, to examine it again in 1797[*]. He found it a combination of the oxide of lead, and an acid with a metallic basis

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[*] *Ann. de Chim.* xxv. 21. and 194.

never before examined. By exposing this acid to a violent heat along with charcoal powder, he reduced it to the metallic state; and to the metal thus obtained he gave the name of *chromium**. The experiments of Vauquelin have been since repeated, and verified by Klaproth †, Gmelin ‡, and Moussin Pouschkin §.

Properties.

Only a very few of the properties of this metal have been ascertained. Its colour is white, with a shade of yellow. It is very brittle, and requires a high temperature for fusion. It is but little altered by exposure to heat, and probably would be affected neither by the action of air nor of water. Acids act upon it but slowly; nitric acid gradually converts it into an oxide by communicating oxygen.

Oxides.

II. Chromium seems capable of combining with three different proportions of oxygen, and of forming three oxides; namely, the *green*, the *brown*, and the *yellow* or *chromic acid.*

1. The protoxide, or green oxide, may be obtained by exposing chromic acid to heat in close vessels; oxygen gas passes over, and the green oxide remains behind.

2. The deutoxide, or brown oxide, is intermediate between the green oxide and chromic acid. Moussin

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* From χρωμα, because it possesses the property of giving colour to other bodies in a remarkable degree.

† Crell's *Annals*, 1798, i. 80. Mr Klaproth had examined the *red lead ore* in consequence of the analysis of Bindheim. His experiments led him to conclude, that the metallic acid, combined with the lead, was not the molybdic, but the acid of some new unknown metal: But his specimen was too small to enable him to decide the point. In the mean time, Vauquelin's experiments were published.

‡ Ibid. 1799, i. 275.

§ Ibid. 1798, i. 355, &c.

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Pouschkin, who first described this oxide, compares it to the brown oxide of iron. He has not given an account of the method by which he obtained it *.

3. The peroxide or chromic acid, is found native in the *red lead ore*. It is a red or orange yellow powder, soluble in water, and composed of 33 parts of chromium and 67 of oxygen.

The remaining properties of chromium have not been examined.

SECT. XXII.

OF COLUMBIUM.

History.

1. In the year 1802, while Mr Hatchett was engaged in arranging some minerals in the British Museum, a dark-coloured heavy substance attracted his attention, on account of some resemblance which it bore to *chromat of iron*. The specimen was small. It was described in Sir Hans Sloane's catalogue as "a very heavy black stone with golden streaks;" and it appears that it was sent along with various specimens of iron ores to Sir Hans Sloane by Mr Winthrop of Massachusets. Its colour was a dark brown grey; its longitudinal fracture imperfectly lamellated, and its cross fracture showed a fine grain. Its lustre was glassy, and in some parts slightly metallic. It was moderately hard, but

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* Crell's *Annals*, 1798, ii. 445.

very brittle. By trituration it yielded a powder of a dark chocolate brown, not attracted by the magnet. Its specific gravity, at the temperature of 65°, was 5.918.

By an ingenious analysis of this mineral, Mr Hatchett ascertained that it was composed of one part of oxide of iron, and rather more than three parts of a white coloured substance which possessed the properties of an acid, and exhibited undoubted proofs of being composed of oxygen united to a metallic basis. The properties of this metallic acid will be described hereafter.

Mr Hatchett demonstrated, that it differs from all the metallic acids hitherto examined; of course its metallic basis must be also peculiar, and required a distinct name. Accordingly he gave it the name of *columbium*.

Attempts to reduce it.

Various attempts were made to reduce this acid to the metallic state, but none of them succeeded completely. A portion of it was put into a crucible lined with charcoal, and exposed to a violent heat in a small wind furnace for about an hour and a half. The oxide was found in a pulverulent state, and had assumed a black colour.

Mr Hatchett ascertained, that, like most of the other metals, it is capable of combining with different doses of oxygen, distinguished from each other by their different colours and different actions upon the acids.

Though strongly heated with sulphur, it showed no disposition to combine with that substance, or to form a sulphuret.

Phosphuret.

In order to form a phosphuret, some phosphoric acid was poured upon a portion of the white oxide; and being evaporated to dryness, the whole was put into a

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crucible lined with charcoal. It was then exposed for half an hour to the heat of a forge. The inclosed matter was spongy, and of a dark brown: it in some measure resembled phosphuret of titanium *.

SECT. XXIII.

OF TANTALIUM.

History.

MR EKEBERG, a Swedish chemist of considerable eminence, has lately discovered a new metal constituting a component part of two minerals, found in the parish of Kimito in Finland. The first of these minerals, which he calls *tantalite*, has a bluish or blackish grey colour, crystallized confusedly, with a metallic lustre and compact fracture. It is very hard, and its specific gravity is 7.953. It has been long known, and mistaken for an ore of tin.

The other mineral, called *yttrotantalite*, is found in small kidney-form masses. It is of a deep grey colour, has a metallic lustre, and a granular fracture. It is not hard. Its specific gravity is 5.130.

From each of these minerals Mr Ekeberg extracted, by a chemical analysis, a white powder, which he ascertained to be the oxide of a peculiar metal, to which he gave the name of *tantalium*.

Reduction.

When this white oxide of tantalium is strongly heat-

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* *Phil. Trans.* 1802.

ed along with charcoal in a crucible, it yields a button moderately hard, which has the metallic lustre externally, but within is black and destitute of brilliancy. The acids convert it again into the state of white coloured oxide.

Oxides

This oxide does not alter its colour, though heated to redness. Its specific gravity is 6.500. It is not acted on by acids, nor is it soluble in any of them. It was this insolubility in acids which induced Ekeberg to give it the name of tantalium, from the fabled punishment of Tantalus.

This oxide combines with the alkalies except ammonia, and forms with them compounds soluble in water. When melted with phosphat of soda and borax*, it forms with them glasses destitute of colour. Such are the only properties of this metal hitherto published†.

The resemblance between the oxides of tantalium and columbium is striking. The only properties in which they differ is the insolubility of the first in acids; but we know not what acids Ekeberg tried, and Mr Hatchett found the oxide of columbium insoluble in nitric acid.

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* These substances will be described afterward.

† Mr Ekeberg's Dissertation is published in the Swedish Transactions for 1802. I have only seen the extracts from it published in the *Journal de Chimie*, iii. 78, and the *Annales de Chimie*, xliii. 276. From these extracts the few properties mentioned in the text have been taken.

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SECT. XXIV.

GENERAL REMARKS.

THE object of the preceding Sections has been to describe the properties of the different metals, and to examine the compounds which they form with oxygen, with simple combustibles, and with each other.

1. The following TABLE exhibits in one view the principal properties of the metals.

Chap. IV

Metals.	Colour.	Hardness.	Specific Gravity.	Fusing Point.	Malleability.	Tenacity.
Gold	Yellow	6½	19.300	32 W.	282000	157
Platinum	White	8	23.000	170+W.		274
Silver	White	7	10.510	28 W.	160000	187
Mercury	White		13.568	−39 F.		
Copper	Red	7½	8.870	27 W.		302
Iron	Blue-grey	9	7.788	158 W.		549
Tin	White	6	7.299	442 F.	2000	31
Lead	Blue-white	5½	11.352	540 F		18
Nickel	White	8½	9.000	150 W.		
Zinc	White	6½	7.190	700 F.		
Bismuth	White	7	9.822	460 F.	0	
Antimony	Grey	6½	6.860	809 F.	0	
Tellurium	White		6.115	540+F.	0	
Arsenic	White	5	8.310	400? F.	0	
Cobalt	White	6	8.150	130 W.	0	
Manganese	White	9	7.000	160 W.	0	
Tungsten	Grey	10	17.600	170+W.	0	
Molybdenum	Grey		7.500		0	
Uranium	Grey	6	6.440		0	
Titanium	Red	9			0	
Chromium	White				0	

W. Wedgewood's pyrometer. F. Fahrenheit's thermometer.

Oxides.

2. All the metals are capable of combining with oxygen, and of course belong to the class of combustible substances. The affinity of each for oxygen is different; for some metals are capable of absorbing oxygen from others, and of decomposing their oxides. The order of the affinity of each metal for oxygen, as far as it has been ascertained, may be seen by inspecting the Table of the affinities of oxygen at the end of the first Chapter of this Book.

It is by no means the metal which has the strongest affinity for oxygen which attracts oxygen most readily from the air. Arsenic, for instance, loses its lustre in a very short time in the open air; yet its affinity for oxygen is not so strong as the affinity of tin, which may be exposed to the air for years without undergoing any considerable oxidation. We would err, therefore, very much, if we were to determine the affinity of metals for oxygen by their absorption of oxygen from the air.

Contain determinate portions of oxygen.

Some metals are capable of combining with only one proportion of oxygen, and consequently of forming one oxide; but the greater number combine with two or three different doses, and form a variety of oxides, which are usually distinguished from each other by their colour. These doses are different for different metals, and for different oxides; but the same proportion of oxygen is always necessary to form the same oxide. In short, every oxide is composed of certain determinate proportions of metal and oxygen, as has been demonstrated by Mr Proust and other chemical philosophers. Hence it follows that metals are not capable of indefinite degrees of oxidation, but only of a certain number; and that every particular oxide consists of a determinate quantity of the metal and of oxygen chemically combined. Iron, for instance, is not capable, as has been supposed, of uniting with oxygen in all the intermediate degrees between 0.27 and 0.48, and consequently of forming 20 or 30 different oxides: it can only combine with precisely 0.27 parts, or 0.48 parts, and with no other proportions ; and therefore is only capable of forming two oxides, the *black* and the *red*. In like manner every other metal combines with certain proportions of oxygen, and forms either two oxides or more according to its nature.

The following TABLE exhibits the number of metallic oxides, and the quantity of oxygen contained in one part of each, as far as this difficult subject has been investigated.

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Table of the Oxides.

Metals.	Oxides	Colours.	Proportion of Oxygen.
Gold	1 2	Purple Yellow	 0.10
Platinum		Yellow	0.07
Silver	1 2	Grey White	0.10
Mercury	1 2 3 4	Black White Red	0.04 0.107 0.15
Copper	1 2	Orange Brown	0.115 0.20
Iron	1 2	Black Red	0.27 0.48
Tin	1 2	Yellow White	0.20 0.28
Lead	1 2 3 4	Grey Yellow Red Brown	 0.09 0.21
Nickel		Green	0.33
Zinc	1 2	Yellow White	0.12 0.20
Bismuth	1 2	Brown White	 0.187
Antimony	1 2	White White	0.185 0.23

Metals.	Oxides	Colour.	Proportion of Oxygen.
Tellurium		White	
Arsenic	1	White	0.248
	2	Acid	0.346
Cobalt	1	Blue	
	2	Green	
	3	Black	
Manganese	1	White	0.20
	2	Red	0.26
	3	Black	0.40
Tungsten	1	Black	
	2	Yellow	0.20
Molybdenum	1	Black	
	2	Blue	
	3	Green	
	4	White	
Uranium		Yellow	0.44
Titanium	1	Blue	
	2	Red	
	3	White	
Chromium	1	Green	
	2	Brown	
	3	Red	0.67
Columbium		White	
Tantalium		White	

Combination of metals with combustibles.

3. One of the simple combustibles is considered at present as incapable of combining with metals; namely, hydrogen. Hydrogen gas indeed, in certain circumstances, dissolves a minute portion of iron, zinc, arsenic, or their oxides, and perhaps also of tin; but these solutions are not permanent. Carbon can only be combined with one metal, namely iron. It is found indeed sometimes in zinc and in manganese, but always combined with iron.

Sulphur combines with all the metals except gold, and perhaps titanium *. Two of the metals when oxidated, namely, tin and zinc, combine with sulphur, and form sulphureted oxides. The metallic sulphurets are all brittle; and most of them are dark-coloured, and destitute of the metallic lustre. Several of them, however, possess great beauty, and have been employed with success as paints.

All the metals hitherto tried are capable of combining with phosphorus, unless bismuth and mercury be exceptions. The metallic phosphurets have been applied to no use: Most of them have the metallic lustre, and all of them are brittle except those of tin, lead, and zinc. In general, both sulphur and phosphorus may be separated from metals by heat.

4. It does not appear that the simple incombustibles are capable of combining with metals; but one of them, namely muriatic acid, combines readily with the metallic oxides.

Alloys.

5. Almost all the metals are capable of combining

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* Proust has proved that platinum is capable of combining with sulphur, and that sulphuret of antimony is found native.—*Ann. de Chim.* xxxviii. 149.

with each other, and of forming alloys; many of which are of the greatest utility in the arts. This property was long reckoned peculiar to metals, and is at present one of the best criterions for determining the metallic nature of any substance. Much is wanting to render the chemistry of alloys complete. Many of them have never been examined; and the proportions of almost all of them are unknown. Neither has any accurate method been yet discovered of determining the affinities of metals for each other. The order of affinities which has been given for each metal was determined by Bergman; but he acknowledges himself that he wanted the proper data to ensure accuracy. These alloys are much better known to artists and manufacturers than to chemists: But an examination of them, guided by the lights which chemistry is now able to furnish, would undoubtedly contribute essentially to the improvement of some of the most important branches of human industry.

Book I.
Division II.

DIVISION II.

OF

UNCONFINABLE BODIES.

THE substances described in the preceding Chapters are of such a nature that they can be collected together in quantities, and retained and confined in proper vessels, in order to be subjected to the test of experiment, and examined with accuracy. But the substances which are now to occupy our attention are very different. We have no method of collecting and retaining them till we submit them to our examination. They are of too subtile a nature to be confined in our vessels, and have too strong an affinity for other bodies to remain a moment in a separate state. These peculiarities have rendered the investigation of them particularly intricate, and have given birth to a great many theories and hypotheses concerning them, which have been supported with much ingenuity and address by several distinguished philosophers. The number of them which are at present known, or supposed to exist, amounts to four; namely, Light, Heat, Electricity, and Magnetism: But the last of these is scarcely at present considered as belonging to chemistry; and the

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third I propose to consider in a separate work. I shall therefore confine myself to the first two bodies, which I shall consider in the following Chapters. Their intimate connection with *combustion*, the most important problem in chemistry, has procured them the highest attention, and rendered the investigation of their properties the most interesting part of chemistry. Let us begin with the consideration of *light*, because its nature has been more completely examined than that of heat, and its properties ascertained with greater precision.

CHAP. I.

OF LIGHT.

EVERY person is acquainted with the light of the sun, the light of a candle, and other burning bodies; and every one knows that it is by means of light that bodies are rendered visible.

Nature of light.

Concerning the nature of *this light*, two different theories have been advanced by philosophers. Huygens considered it as a subtile fluid filling space, and rendering bodies visible by the undulations into which it is thrown. According to his theory, when the sun rises it agitates this fluid, the undulations gradually extend themselves, and at last, striking against our eye, we see the sun. This opinion of Huygens was adopted also by Euler, who exhausted the whole of his consummate mathematical skill in its defence.

The rest of philosophers, with Newton at their head, consider light as a substance consisting of small particles, constantly separating from luminous bodies, moving in straight lines, and rendering bodies luminous by passing from them and entering the eye. Newton established this theory on the firm basis of mathematical demonstration; by shewing that all the phenomena of light may be mathematically deduced from it. Huygens and Euler, on the contrary, attempted to support their hypothesis, rather by starting objections to the theory of Newton, than by bringing forward direct proofs. Their objections, even if valid, instead of establishing their own opinions, would prove only that the phenomena of light are not completely understood; a truth which no man will refuse to acknowledge, whatever side of the question he adopts. Newton and his disciples, on the contrary, have shewn, that the known phenomena of light are *inconsistent* with the undulations of a fluid, and that on such a supposition there can be no such thing as darkness at all. They have also brought forward a great number of direct arguments, which it has been impossible to answer, in support of their theory. The Newtonian theory therefore is much more probable than the other. Taking it for granted, then, that light is constantly moving in straight lines from luminous bodies, let us proceed to examine its properties.

Its velocity.

1. It was first demonstrated by Roemer *, a Danish philosopher, that light takes about eight minutes in moving across one half of the earth's orbit; consequently it moves at the rate of nearly 200,000 miles in a second. The discovery of Roemer has been still farther confirmed and elucidated by Dr Bradley's very ingenious theory of the aberration of the light of the fixed stars †.

Size of its particles.

2. From this astonishing velocity we are enabled to form some notion of the size of the particles of light. Mechanical philosophers have demonstrated, that the

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* *Phil. Trans.* xii. 33.

† Ibid. xxxv. 637, and xlv. 1.

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force with which a body strikes another depends upon its size and the velocity with which it moves. A 24 pound ball, if thrown from the hand, makes no impression upon a common wall; but, when discharged from a cannon, with the velocity of 1300 feet in a second, it will shatter the wall to pieces. The greater the velocity, therefore, with which a body moves, the greater the effect which it is capable of producing. Consequently to produce any effect whatever by a body, however small, we have only to increase its velocity sufficiently; and in order to prevent a body from producing a given effect, its quantity must be diminished in proportion as its velocity is increased. Now the velocity of light is so great, that if each of its particles weighed the 1000th part of a grain, its force would be greater than that of a bullet discharged from a musket. Were it even the millionth part of a grain in weight, it would destroy every thing against which it struck. If it even weighed the millionth part of that, it would still have a very sensible force. But how much less must be the weight of a particle of light, which makes no sensible impression upon so delicate an organ as the eye? We are certain, then, that no particle of light weighs $\frac{1}{1,000,000,000,000}$th of a grain; but were we even to suppose it of that size, the addition of 9000 millions of particles to any body, or their abstraction, would make no difference of weight capable of being detected by the most sensible balance. Every attempt then to ascertain the accumulation of light in bodies by changes in their weight must be hopeless.

Refraction.

While a ray of light is passing through the same medium, or when it passes perpendicularly from one medium to another, it continues to move without changing its direction; but when it passes obliquely from one medium to another of a different density, it always bends a little from its old direction, and assumes a new one. It is then said to be *refracted*. When it passes into a denser medium, it is refracted *towards* the perpendicular; but when it passes into a rarer medium, it is refracted *from* the perpendicular. In general the quantity of refraction is proportional to the density of the medium; but if the medium be combustible, the refraction is greater than it would otherwise be *. In the same medium the sines of the angles of incidence and of refraction have always the same ratio to each other.

Reflection.

4. When a ray of light enters a transparent medium, as a plate of glass with a certain obliquity, it continues to move on till it comes to the opposite surface of the glass; but then, instead of passing through the glass, it bends, and passes out again at the same surface at which it entered; just as a ball would do if made to strike obliquely against the floor. The ray is then said to be *reflected*. The angle of reflection is always equal to the angle of incidence. When the surface of a medium is polished, as glass or mirrors, oblique rays do not enter them at all, but are *reflected* when they approach the surface of the body. All surfaces are capable of reflecting a greater or smaller number of oblique rays. Rays are only reflected at surfaces.

Inflection.

5. When a ray of light passes within a certain distance of a body parallel to which it is moving, it is

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* It was the knowledge of this law that led Newton to suspect the diamond to be combustible, and water to contain a combustible ingredient.—*Optics*, p. 270.

bent *towards* it. Thus if a ray of light be let into a dark room through a small hole in the window-shutter, and received upon paper, it will form a round luminous spot. If two penknives, with their edges towards each other, be placed on opposite sides of the hole, and made to approach each other, the luminous spot will gradually dilate itself on the side of the knives, indicating that those rays which pass nearest the knives have been drawn from their former direction towards the knives. This property of light is called *inflection*.

Deflection.

6. The ray, when its distance from the body parallel to which it moves is somewhat greater, is bent *from* it. It is then said to be *deflected*.[*]

Newton has demonstrated, that these phenomena are owing to the attraction between light and the medium through which it is moving, the medium towards which it is approaching, or the bodies in its neighbourhood.

Opacity and transparency.

7. Some substances, as water, are *transparent*, or allow light to pass freely through them; others, as iron, are *opaque*, or allow no light to pass through them. Now, it can scarcely be doubted that the component particles of all bodies are far enough distant from each other to allow the free transmission of light; consequently opacity and transparency must depend, not upon the distance of the particles of bodies, but upon something else. Newton has shown, that transparency can only be explained by supposing the particles of transparent bodies uniformly arranged and of equal density. When a ray of light enters such a body, being attracted equally in every direction, it is in the same state as if it were not attracted at all, and therefore passes through the body without obstruction. In opaque bodies, on the contrary, the particles are either not uni-

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formly arranged, or they are of unequal density. Hence the ray is unequally attracted, obliged constantly to change its direction, and cannot therefore make its way through the body.

Decomposable into seven rays.

8. When a ray of light is made to pass through a triangular prism, and received upon a sheet of white paper, the image, or *spectrum* as it is called, instead of being circular, is oblong, and terminated by semicircular arches. In this case the refraction of the light is increased considerably by the figure of the prism. Consequently if light consists of a congeries of rays differing in refrangibility, they will be separated from each other: the least refrangible occupying the luminous circle which the ray would have formed had it not been for the prismatic form of the glass; the others going to a greater or smaller distance from this circle, according to their refrangibility. The oblong figure of the spectrum is a proof that light consists of rays differently refrangible; and as the spectrum exhibits seven colours, these rays have been reduced under seven classes. The colours are in the following order; RED, ORANGE, YELLOW, GREEN, BLUE, INDIGO, VIOLET. The red is the least refrangible, the violet the most; the others are refrangible in the order in which they have been named. Newton ascertained, by actual measurement, that if the whole of the spectrum be divided into 360 parts, then

The red will occupy	45 of these parts
orange	27
yellow	48
green	60
blue	60
indigo	40
violet	80

But they have been since observed to differ somewhat in their relative lengths in the spectrum, according to the refracting medium.

9. These coloured rays differ from each other in reflexibility and inflexibility, precisely as they do in refrangibility: the red rays being least reflexible and inflexible, the violet most, and the rest according to their order in the prismatic spectrum.

10. Every one of these coloured rays is permanent; not being affected nor altered by any number of refractions or reflections.

The properties of light now enumerated constitute the object of the science called OPTICS. They prove, in the most decisive manner, that light is attracted by other bodies; and not only attracted, but attracted unequally. For combustible bodies, provided all other things be equal, refract light more powerfully than other bodies, and consequently attract light more powerfully. But it is *variation*, in point of strength, which constitutes the characteristic mark of chemical affinity. Hence it follows that the attraction which subsists between light and other bodies does not differ from chemical affinity. The importance of this remark will be seen hereafter.

Illuminating power of each.

11. The rays of light differ in their power of illuminating objects: For if an equal portion of each of these rays, one after another, be made to illuminate a minute object, a printed page for instance, it will not be seen distinctly at the same distance when illuminated by each. We must stand nearest the object when it is illuminated by the violet: we see distinctly at a somewhat greater distance when the object is illuminated by the indigo ray; at a greater, when by the blue; at a still

greater, when by the deep green; and at the greatest of all, when by the lightest green or deepest yellow: we must stand nearer when the object is enlightened by the orange-ray, and still nearer when by the red. Thus it appears that the rays towards the middle of the spectrum possess the greatest illuminating power, and those at the extremity the least; and that the illuminating power of the rays gradually diminishes from the middle of the spectrum towards its extremities. For these facts we are indebted to the experiments of Dr Herschel *.

Light enters bodies,

12. Light is capable of entering into bodies and remaining in them, and of being afterwards extricated without any alteration. Father Beccaria, and several other philosophers, have shewn us, by their experiments, that there are a great many substances which become luminous after being exposed to the light †. This property was discovered by carrying them instantly from the light into a dark place, or by darkening the chamber in which they are exposed. Most of these substances, indeed, lose this property in a very short time, but they recover it again on being exposed to the light; and this may be repeated as often as we please. We are indebted to Mr Canton for some very interesting experiments on this subject, and for discovering a composition which possesses this property in a remarkable degree ‡. He calcined some common oyster shells in a good coal fire for half an hour, and then pounded and sifted the purest part of them. Three parts of this

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* *Phil. Trans.* 1800, p. 255.

† Ibid. lxi. 212.

‡ Ibid. lviii. 337.

powder were mixed with one part of the flowers of sulphur, and rammed into a crucible which was kept red hot for an hour. The brightest parts of the mixture were then scraped off, and kept for use in a dry phial well stopped *. When this composition is exposed for a few seconds to the light, it becomes sufficiently luminous to enable a person to distinguish the hour on a watch by it. After some time it ceases to shine, but recovers this property on being again exposed to the light. Light then is not only acted upon by other bodies, but it is capable of uniting with them, and afterwards leaving them without any change.

It is well known that light is emitted during combustion; and it has been objected to this conclusion, that these bodies are luminous only from a slow and imperceptible combustion. But surely combustion cannot be suspected in many of Father Beccaria's experiments, when we reflect that one of the bodies on which they were made was his own hand, and that many of the others were altogether incombustible; and the phenomena observed by Mr Canton are also incompatible with the notion of combustion. His pyrophorus shone only in consequence of being exposed to light, and lost that property by being kept in the dark. It is not exposure to light which causes substances capable of combustion at the temperature of the atmosphere to become luminous, but exposure to air. If the same temperature continues, they do not cease to shine till they are

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* Dr Higgins has added considerable improvements to the method of preparing Canton's pyrophorus. He stratifies the oyster shells and sulphur in a crucible without pounding them; and after exposing them to the proper heat, they are put into phials furnished with ground-stoppers.

consumed; and if they cease, it is not the application of light, but of caloric, which renders them again luminous: but Canton's pyrophorus, on the contrary, when it had lost its property of shining, did not recover it by the application of heat, except it was accompanied by light. The only effect which heat had was to increase the separation of light from the pyrophorus, and of course to shorten the duration of its luminousness. Two glass globes, hermetically sealed, containing each some of this pyrophorus, were exposed to the light and carried into a dark room. One of them, on being immersed in a bason of boiling water, became much brighter than the other, but in ten minutes it ceased to give out light: the other remained visible for more than two hours. After having been kept in the dark for two days, they were both plunged into a bason of hot water; the pyrophorus which had been in the water formerly did not shine, but the other became luminous, and continued to give out light for a considerable time. Neither of them afterwards shone by the application of hot water; but when brought near to an iron heated so as scarcely to be visible in the dark, they suddenly gave out their remaining light, and never shone more by the same treatment: but when exposed a second time to the light, they exhibited over again precisely the same phenomena; even a lighted candle and electricity communicated some light to them. Surely these facts are altogether incompatible with combustion, and fully sufficient to convince us that light alone was the agent, and that it had actually entered into the luminous bodies.

It has been questioned, indeed, whether the light emitted by pyrophori be the same with that to which they are exposed. Mr Wilson has proved, that in many cases at least it is different; and in particular that on many pyrophori the blue rays have a greater effect than any other, and that they cause an extrication of red light. Mr de Grosser has shewn the same thing with regard to the diamond, which is a natural pyrophorus*. Still, however, it cannot be questioned that the luminousness of these bodies is owing to exposure to light, and that the phenomenon is not connected with combustion.

And combines with them.

13. But light does not only enter into bodies, it also combines with them, and constitutes one of their component parts. That this is the case, has been rendered very evident by a set of experiments made long ago by Mr Canton†, and lately repeated and carried a great deal farther by Dr Hulme‡. It has been long known that different kinds of meat and fish, just when they are beginning to putrefy, become luminous in the dark, and of course give out light. This is the case in particular with the whiting, the herring, and the mackerel. When four drams of either of these are put into a phial containing two ounces of sea water, or of pure water holding in solution $\frac{1}{2}$ dram of common salt, or two drams of sulphat of magnesia, if the phial be put into a dark place, a luminous ring appears on the surface of the liquid within three days, and the whole liquid, when agitated, becomes luminous, and continues in that state for some time. When these liquids are frozen, the light disappears, but is again emitted as soon as

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* *Jour. de Phys.* xx. 270.

† *Phil. Trans.* lix. 446.

‡ Ibid. 1800. p. 161.

they are thawed. A moderate heat increases the luminousness, but a boiling heat extinguishes it altogether. The light is extinguished also by water, lime water, water impregnated with carbonic acid gas, or sulphureted hydrogen gas, fermented liquors, spirituous liquors, acids, alkalies, and water saturated with a variety of salts, as sal-ammoniac, common salt, sulphat of magnesia; but the light appears again when these solutions are diluted with water. This light produces no sensible effect on the thermometer *. After these experiments, it can scarcely be denied that light constitutes a component part of these substances, and that it is the first of the constituent parts which makes its escape when the substance containing it is beginning to be decomposed.

Colour explained.

14. Almost all bodies have the property of absorbing light, though they do not all emit it again like the pyrophori and animal bodies. But they by no means absorb all the rays indiscriminately; some absorb one coloured ray, others another, while they reflect the rest. This is the cause of the different colours of bodies. A red body, for instance, reflects the red rays, while it absorbs the rest; a green reflects the green rays, and perhaps also the blue and the yellow, and absorbs the rest. A white body reflects all the rays, and absorbs none; while a black body, on the contrary, absorbs all the rays, and reflects none. The different colours of bodies, then, depend upon the affinity of each for particular rays, and its want of affinity for the others.

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* The same experiments succeed with Canton's pyrophorus, as Dr Hulme has shewn.

Book I. Division II.

Light produces changes on bodies.

15. The absorption of light by bodies produces very sensible changes in them. Plants, for instance, may be made to vegetate tolerably well in the dark; but in that case their colour is always white, they have scarcely any taste, and contain but a very small proportion of combustible matter. In a very short time, however, after their exposure to light, their colour becomes green, their taste is rendered much more intense, and the quantity of combustible matter is considerably increased*. These changes are very obvious, and they de-

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* The following very curious observation by Professor Robison deserves particular attention: "Having occasion, in autumn 1774, to go down and inspect a drain in a coalwork, where an embankment had been made to keep off a lateral run of water, and, crawling along, I laid my hand on a very luxuriant plant, having a copious, deep-indented, white foliage, quite unknown to me. I inquired of the colliers what it was? None of them could tell me. It being curious, I made a sod be carried up to the day-light, to learn of the workmen what sort of a plant it was. But nobody had ever seen any like it. A few days after, looking at the sod, as it lay at the mouth of the pit, I observed that the plant had languished and died for want of water, as I imagined. But looking at it more attentively, I observed that a new vegetation was beginning, with little sproutings from the same stem, and that this new growth was of a green colour. This instantly brought to my recollection the curious observations of Mr Dufay; and I caused the sod to be set in the ground, and carefully watered. I was the more incited to this, because I thought that my fingers had contracted a sensible aromatic smell by handling the plant at this time. After about a week, this root set out several stems and leaves of common tansy. The workmen now recollected that the sods had been taken from an old cottage garden hard by, where a great deal of tansy was still growing among the grass. I now sent down for more of the same stuff, and several sods were brought up, having the same luxuriant white foliage. This, when bruised between the fingers, gave no aromatic smell whatever. All these plants withered and died down, though carefully watered, and, in each, there sprouted from the same stocks fresh stems, and a copious foliage, and produced, among others, common tansy, fully impregnated with the or-

pend incontestibly upon the agency of light. Another very remarkable instance of the agency of light is the reduction of the metallic oxides. The red oxide of mercury and of lead become much lighter when exposed to the sun; and the white salts of silver, in the same situation, soon become black, and the oxide is reduced. The oxide of gold may be reduced in the same manner. Light, then, has the property of separating oxygen from several of the oxides. Scheele, who first attended accurately to these facts, observed also, that the violet ray reduces the oxide of silver sooner than any of the other rays[*]; and Sennebier has ascertained, that the same ray has the greatest effect in producing the green colour of plants[†]. Berthollet observed, that during the reduction of the oxides, a quantity of oxygen gas makes its escape[‡].

Contains deoxidizing rays, not colorific.

It was supposed till lately, that those reductions of metallic oxides were produced by the calorific rays of light; but Messrs Wollaston, Ritter, and Bockmann, have lately ascertained, that muriat of silver is black-

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dinary juices of that plant, and of a full green colour. I have repeated the same experiment with great care on lovage (*levisticum vulgare*), mint, and caraways. As these plants throve very well below, in the dark, but with a blanched foliage, which did not spread upwards, but lay flat on the ground; in all of them there was no resemblance of shape to the ordinary foliage of the plant. All of them died down when brought into day-light; and the stocks then produced the proper plants in their usual dress, and having all their distinguishing smells."—Dr Black's *Lectures*, i. 532.

[*] On *Fire*, p. 78. and 98.

[†] *Mem. Physico-chim.* ii. 72.

[‡] *Jour. de Phys.* xxix. 81. When muriat of silver is exposed to the solar light, it blackens almost instantaneously. In that case it is not oxygen gas which is emitted, but muriatic acid, as has been observed also by Berthollet. See *Jour. de Phys.* lvi. 80.

ened most rapidly when it is placed beyond the violet ray, and entirely out of the prismatic spectrum. Hence it follows, that the change is produced, not merely by the colorific rays, but by rays which are incapable of rendering objects visible; neither do they produce any sensible heat. We see that they are more refrangible than the colorific rays, as they extend beyond the violet end of the spectrum. From these remarkable experiments it follows, that the solar light is composed of at least two sets of rays; one set which renders bodies visible, and another set which blackens muriat of silver, and reduces metallic oxides. It is by no means unlikely, that all the other chemical changes produced on bodies by solar light, is owing to the second set of rays, which hitherto have obtained no name. As the effect of the different prismatic colours on metallic oxides increases with their refrangibility, and as the effect is greatest at a certain distance beyond the violet ray, we can scarcely hesitate to admit, that the colorific rays have no influence whatever in the phenomena; but that it is owing to the other or *deoxidizing* rays, which of course are mixed with the colorific, and increase in quantity with the refrangibility. We shall find afterwards that solar light, besides these two sets, contains also a third species of ray, different from both in its nature and effects.

Light possess three peculiar properties.

16. Such are the properties of light as far as they have been examined. They are sufficient to induce us to believe that it is a body, and that it possesses many qualities in common with other bodies. It is attracted by them, and combines with them precisely as other bodies do. But it is distinguished from all the substances hitherto described, by possessing three peculiar properties, of

which they are destitute. The first of these properties is the power which it has of exciting in us the sensation of vision, by moving from the object seen, and entering the eye. The phenomena of colours, and the prismatic spectrum, indicate the existence of seven different species of light; but to what the difference of these species is owing, has not been ascertained. We are altogether ignorant of the component parts of every one of these species.

The second peculiar property of light is the prodigious velocity with which it moves whenever it is separated from any body with which it was formerly combined. This velocity, which is but little less than 200,000 miles in a second, it acquires in a moment; and it seems to acquire it too in all cases, whatever the body be from which it separates.

The third, and not the least singular of its peculiar properties, is, that its particles are never found cohering together, so as to form masses of any sensible magnitude. This difference between light and other bodies can only be accounted for by supposing that its particles repel each other. This seems to constitute the grand distinction between light and the bodies hitherto described. Its particles *repel* each other, while the particles of the other bodies attract each other; and accordingly are found cohering together in masses of more or less magnitude.

Sources of light.

17. It now only remains to consider the different methods by which light may be procured; or, to speak more precisely, the different sources from which light is emitted in a visible form. These sources are four: 1. The sun and stars; 2. Combustion; 3. Heat; and, 4. Percussion.

Book. I. Division II.

1. The sun.

The light emitted by the sun is familiarly known by the names of *sunshine* and *light of day*. The light of the stars, as has been ascertained, possesses precisely the same properties. With respect to the cause why the sun and stars are constantly emitting light, the question will probably for ever baffle the human understanding; at any rate, it is not considered as connected with the science of chemistry.

2. Combustion.

18. Light is emitted in every case of *combustion.* Now combustion, as far at least as regards simple combustibles and metals, is the act of combination of the combustible with oxygen. Consequently the light which is emitted during combustion must have existed previously combined either with the combustible or with the oxygen. But this subject will be resumed in the next Chapter, where the nature of combustion will be particularly considered.

3. Heat.

19. If heat be applied to bodies, and continually increased, there is a certain temperature at which, when they arrive, they become luminous. No fact is more familiar than this; so well known indeed is it, that little attention has been paid to it. When a body becomes luminous by being heated in a fire, it is said in common language to be *red hot*. As far as experiments have been made upon this subject, it appears that all bodies which are capable of enduring the requisite degree of heat without decomposition or volatilization begin to emit light at precisely the same temperature. The first person who examined this subject with attention was Sir Isaac Newton. He ascertained, by a very ingenious set of experiments, first published in 1701, that iron is just visible in the dark when heated to 635°; that it shines strongly in the dark when raised

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to the temperature of 752° ; that it is luminous in the twilight just after sunset when heated to 884° ; and that when it shines, even in broad day-light, its temperature is above 1000°. From the experiments of Muschenbroeck and others, it appears, that what in common language is called a *red heat*, commences about the temperature of 800°.

A red hot body continues to shine for some time after it has been taken from the fire and put into a dark place. The constant accession, then, either of light or heat, is not necessary for the shining of bodies : but if a red hot body be blown upon by a strong current of air, it immediately ceases to shine *. Consequently the moment the temperature of a body is diminished by a certain number of degrees, it ceases to be luminous.

Whenever a body reaches the proper temperature, it becomes luminous, independent of any contact of air ; for a piece of iron wire becomes red hot while immersed in melted lead †.

To this general law there is one remarkable exception : It does not appear that the gases become luminous even at a much higher temperature. The following ingenious experiment of Mr T. Wedgewood seems to set the truth of this exception in a very clear point of view. He took an earthen ware tube B (fig. 9.), bent so in the middle that it could be sunk, and make several turns in the large crucible C, which was filled with sand. To one end of this tube was fixed the pair of bellows A ; at the other end was the globular vessel, D, in which was the passage F, furnished with a valve

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* T. Wedgewood, *Phil. Trans.* 1792.

† Id. Ibid.

to allow air to pass out, but none to enter. There was another opening in this globular vessel filled with glass, that one might see what was going on within. The crucible was put into a fire; and after the sand had become red hot, air was blown through the earthen tube by means of the bellows. This air, after passing thro' the red hot sand, came into the globular vessel. It did not shine; but when a piece of gold wire E was hung at that part of the vessel where the earthen ware tube entered, it became faintly luminous: a proof that, though the air was not luminous, it had been hot enough to raise other bodies to the shining temperature.

4. Percussion.

19. The last of the sources of light is *percussion*. It is well known, that when flint and steel are smartly struck against each other, a spark always makes its appearance, which is capable of setting fire to tinder or to gunpowder. The spark in this case, as was long ago ascertained by Dr Hooke, is a small particle of the iron which is driven off, and catches fire during its passage through the air. This, therefore, and all similar cases, belong to the class of combustion. But light often makes its appearance when two bodies are struck against each other, when we are certain that no such thing as combustion can happen, because both the bodies are incombustible. Thus, for instance, sparks are emitted, when two quartz stones are struck smartly against each other, and light is emitted when they are rubbed against each other. The experiment succeeds equally well under water. Many other hard stones also emit sparks in the same circumstances.

If they be often made to emit sparks above a sheet of white paper, there are found upon it a number of small black bodies, not very unlike the eggs of flies.

These bodies are hard but friable, and when rubbed on the paper leave a black stain. When viewed with a microscope, they seem to have been melted. Muriatic acid changes their colour to a green, as it does that of lavas[*]. These substances evidently produced the sparks by being heated red hot. Lamanon supposes that they are particles of quartz combined with oxygen. Were that the case, the phenomenon would be precisely similar to that which is produced by the collision of flint and steel. That they are particles of quartz cannot be doubted; but to suppose them combined with oxygen is contrary to all experience; for these stones never shew any disposition to combine with oxygen even when exposed to the most violent heat. La Metherie made experiments on purpose to see whether Lamanon's opinion was well founded; but they all turned out unfavourable to it. And Monge ascertained, that the particles described by Lamanon were pure crystal unaltered, with a quantity of black powder adhering to them. He concludes, accordingly, that these fragments had been raised to so high a temperature during their passage through the air, that they set fire to all the minute bodies that came in their way[†]. The emission of the light is accompanied by a very peculiar smell, having some analogy to that of burning sulphur, or more nearly to burning gunpowder.

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[*] Lamanon, Jour. de Phys. 1785.

[†] Ann. de Chim. xvi. 226.

CHAP. II.

OF CALORIC.

Definition.

NOTHING is more familiar to us than *heat;* to attempt therefore to define it is unnecessary. When we say that *a person feels heat*, that *a stone is hot*, the expressions are understood without difficulty; yet in each of these propositions the word *heat* has a distinct meaning. In the one, it signifies the *sensation of heat;* in the other, the *cause* of that sensation. This ambiguity, though of little consequence in common life, leads unavoidably in philosophical discussions to confusion and perplexity. It was to prevent this that the word *caloric* has been chosen to signify the *cause of heat*. When I put my hand on a hot stone, I experience a certain sensation, which I call the *sensation of heat;* the cause of this sensation is *caloric*.

As the phenomena in which caloric is concerned are the most intricate and interesting in chemistry; as the study of them has contributed in a very particular manner to the advancement of the science; as they involve some of those parts of it which are still exceedingly obscure, and which have given occasion to the most important disputes in which chemists have been engaged—they naturally lay claim to a very particular attention.

Division.

I shall divide this Chapter into six Sections: The first will be occupied with the nature of caloric; in the second, I shall consider its propagation through bodies; in the third, its distribution; in the fourth, the effects which it produces on bodies; in the fifth, the quantity of it which exists in bodies; and in the sixth, the different sources from which it is obtained.

SECT. I.

NATURE OF CALORIC.

Concerning the nature of caloric, there are two opinions which have divided philosophers ever since they turned their attention to the subject. Some suppose that caloric, like gravity, is merely a property of matter, and that it consists, some how or other, in a peculiar vibration of its particles; others, on the contrary, think that it is a distinct substance. Each of these opinions has been supported by the greatest philosophers; and till lately the obscurity of the subject has been such, that both sides have been able to produce exceedingly plausible and forcible arguments. The recent improvements, however, in this branch of chemistry, have gradually rendered the latter opinion much more probable than the former: And a recent discovery, made by Dr Herschel, has at last nearly put an end to the dispute, by demonstrating, that caloric is not a property, but a peculiar substance; or at least that we have the same reason for considering it to be a substance, as we have for the believing light to be material.

Discovery of rays of caloric.

1. Dr Herschel had been employed in making observations on the sun by means of telescopes. To prevent the inconvenience arising from the heat, he used coloured glasses; but these glasses, when they were deep enough coloured to intercept the light, very soon cracked and broke in pieces. This circumstance induced him to examine the heating power of the different coloured rays. He made each of them in its turn fall upon the bulb of a thermometer, near which two other thermometers were placed to serve as a standard. The number of degrees, which the thermometer exposed to the coloured ray rose above the other two thermometers, indicated the heating power of that ray. He found that the most refrangible rays have the least heating power; and that the heating power gradually increases as the refrangibility diminishes. The violet ray therefore has the smallest heating power, and the red ray the greatest. Dr Herschel found that the heating power of the violet, green, and red rays, are to each other as the following numbers;

Violet = 16
Green = 22.4
Red = 55

It struck Dr Herschel as remarkable, that the illuminating power and the heating power of the rays follow such different laws. The first exists in greatest perfection in the middle of the spectrum, and diminishes as we approach either extremity; but the second increases constantly from the violet end, and is greatest at the red end. This led him to suspect that perhaps the heating power does not stop at the end of the visible spectrum, but is continued beyond it. He placed the thermometer completely beyond the boundary of the red ray, but still in the line of the spectrum; and it rose still higher than it had done when exposed to the red ray. On shifting the thermometer still farther, it continued to rise; and the rise did not reach its maximum till the thermometer was half an inch beyond the utmost extremity of the red ray. When shifted still farther, it sunk a little; but the power of heating was sensible at the distance of 1½ inch from the red ray.

These important experiments have been lately repeated and fully confirmed by Sir Henry Englefield *, in the presence of some very good judges. The apparatus was very different from that of Dr Herschel, and contrived on purpose to obviate certain objections which had been made to the conclusions drawn by that illustrious philosopher. The bulbs of the thermometers used were mostly blackened. The following TABLE exhibits the result obtained in one of these experiments.

Thermometer in the blue ray rose in	3′ from	55° to	56°
green	3	54	58
yellow	3	56	62
full red	2½	56	72
confines of red	2½	58	73½
beyond the visible light	2½	61	79

The thermometer, with its bulb blackened, rose much more when placed in the same circumstances, than the thermometer whose bulb was either naked or whitened with paint. This will be apparent from the following TABLE:

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* *Journal of the Royal Institution*, i. 202.

		Time.	From	To
Red ray	Black therm. White therm.	3′	58° 55	61° 58
Dark	Black therm. White therm.	3	59 58	64 58½
Confines of red	Black therm. White therm.	3	59 57½	71 60½

Both Dr Herschel and Sir Henry Englefield take notice of a faint blush of red, of a semioval form, visible when the rays beyond the red end of the spectrum were collected by a lense.

From these experiments it follows, that there are rays emitted from the sun, which produce heat, but have not the power of illuminating; and that these are the rays which produce the greatest quantity of heat. Consequently *caloric* is emitted from the sun in rays, and the rays of caloric are not the same with the rays of light.

On examining the other extremity of the spectrum, Dr Herschel ascertained that no rays of caloric can be traced beyond the violet ray. He had found, however, as Sennebier had done before him, that all the coloured rays of the spectrum have the power of heating: it may be questioned therefore whether there be any rays which do not *warm*. The coloured rays must either have the property of exciting heat as rays of light, or they must derive that property from a mixture of rays of caloric. If the first of these suppositions were true, light ought to excite heat in all cases; but it has been long known to philosophers that the *light* of the *moon* does not produce the least sensible heat, even when concentrated so strongly as to surpass, in point of illumination, the brightest candles or lamps, and yet these produce a very sensible heat. Here then are rays of light which do not produce heat: rays, too, composed of all the seven prismatic coloured rays. We must conclude, from this well-known fact, that rays of light do not excite heat; and consequently that the coloured rays from the sun and combustible bodies, since they excite heat, must consist of a mixture of rays of light and rays of caloric. That this is the case was demonstrated long ago by Dr Hooke * and afterwards by Scheele †, who separated the two species from each other by a very simple method. If a glass mirror be held before a fire, it reflects the rays of light, but not the rays of caloric; a metallic mirror, on the other hand, reflects both. The glass mirror becomes hot; the metallic mirror does not alter its temperature. If a plate of glass be suddenly interposed between a glowing fire and the face, it intercepts completely the warming power of the fire, without causing any sensible diminution of its brilliancy; consequently it intercepts the rays of caloric, but allows the rays of light to pass. If the glass be allowed to remain in its station till its temperature has reached its maximum, in that situation it ceases to intercept the rays of caloric, but allows them to pass as freely as the rays of light. This curious fact, which shews us that glass only intercepts the rays of caloric till it be saturated with them, was discovered long ago by Dr Robison, professor of natural philosophy in the university of Edinburgh. These facts are sufficient to convince us that the rays of

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* Birche's *History of the Royal Society*, iv. 137.

† *On Fire*, p. 70. Eng. Edit.

light and of caloric are different, and that the coloured rays derive their heating power from the rays of caloric which they contain. Thus it appears that solar light is composed of three sets of rays, the colorific, the calorific, and the deoxidizing.

Refracted.

2. The rays of caloric are refracted by transparent bodies just as the rays of light. We see, too, that, like the rays of light, they differ in their refrangibility; that some of them are as refrangible as the violet rays, but that the greater number of them are less refrangible than the red rays. Whether they are transmitted through all transparent bodies has not been ascertained; neither has the difference of their refraction in different mediums been examined. We are certain, however, that they are transmitted and refracted by all transparent bodies which have been employed as burning-glasses. Dr Herschel has also proved, by experiment, that it is not only the caloric emitted by the sun which is refrangible, but likewise the rays emitted by common fires, by candles, by hot iron, and even by hot water.

Reflected.

3. The rays of caloric are reflected by polished surfaces in the same manner as the rays of light. This was lately proved by Herschel; but it had been demonstrated long before by Scheele, who had even ascertained that the angle of their reflection is equal to the angle of their incidence. Mr Pictet also had made a set of very ingenious experiments on this subject, about the year 1790, which led to the same conclusion *. He placed two concave mirrors of tin, of nine inches focus,

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* A similar set of experiments had been made by Mr King as early as 1785: See his *Morsels of Criticism*, vol. 1st.

at the distance of twelve feet two inches from one another. In the focus of one of them he placed a ball of iron two inches in diameter, heated so as not to be visible in the dark; in the other was placed the bulb of a thermometer. In six minutes the thermometer rose 22°. A lighted candle, which was substituted for the ball of iron, produced nearly the same effect. In this case both light and heat appeared to act. In order to separate them, he interposed between the two mirrors a plate of clear glass. The thermometer sunk in nine minutes 14°; and when the glass was again removed, it rose in seven minutes about 12°; yet the light which fell on the thermometer did not seem at all diminished by the glass. Mr Pictet therefore concluded, that the caloric had been reflected by the mirror, and that it had been the cause of the rise of the thermometer. In another experiment, a glass matrass was substituted for the iron ball, nearly of the same diameter with it, and containing 2044 grains of boiling water. Two minutes after a thick screen of silk, which had been interposed between the two mirrors, was removed, the thermometer rose from 47° to $50\frac{1}{8}$, and descended again the moment the matrass was removed from the focus.

The mirrors of tin were now placed at the distance of 90 inches from each other; the matrass with the boiling water in one of the foci, and a very sensible air thermometer in the other, every degree of which was equal to about $\frac{1}{11}$th of a degree of Fahrenheit. Exactly in the middle space between the two mirrors there was placed a very thin common glass mirror, suspended in such a manner that either side could be turned towards the matrass. When the polished side of this mirror was turned to the matrass, the thermometer rose only 0.5°; but when the side covered with tinfoil, and which had been blackened with ink and smoke, was turned towards the matrass, the thermometer rose to 3.5°. In another experiment, when the polished side of the mirror was turned to the matrass, the thermometer rose 3°, when the other side 9.2°. On rubbing off the tinfoil, and repeating the experiment, the thermometer rose 18°. On substituting for the glass mirror a piece of thin white pasteboard of the same dimensions with it, the thermometer rose 10 *.

Their velocity.

4. As the rays of light and of caloric emitted by the sun accompany each other, it cannot be doubted that they move with the same velocity. The rays of caloric, therefore, move at the rate of almost 200,000 miles in a second. This is confirmed by an experiment of Mr Pictet. He placed two concave mirrors at the distance of 69 feet from each other; the one of tin as before, the other of plaster gilt, and 18 inches in diameter. Into the focus of this last mirror he put an air thermometer, and a hot bullet of iron into that of the other. A few inches from the face of the tin mirror there was placed a thick screen, which was removed as soon as the bullet reached the focus. The thermometer rose the instant the screen was removed without any perceptible interval; consequently the time which caloric takes in moving 69 feet is too minute to be measured †. We see at once that this must be the case when we recollect that caloric moves at the rate of 200,000 miles in a second.

Size.

5. The velocity of caloric being equal to that of light,

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* Pictet, *sur le Feu*, chap. iii.

† Ibid.

its particles must be equally minute. Therefore neither the addition of caloric nor its abstraction can sensibly affect the weight of bodies. As this follows necessarily as a consequence from Dr Herschel's experiments, were it possible to prove by experiment that caloric affects the weight of bodies, the theory founded on Dr Herschel's discoveries would be overturned: But such deductions have been drawn from the experiments of De Luc *, Fordyce †, Morveau ‡, and Chaussier §. According to these philosophers, bodies become absolutely lighter by being heated. The experiment of Fordyce, which seems to have been made with the greatest care, was conducted in the following manner:

He took a glass globe three inches in diameter, with a short neck, and weighing 451 grains; poured into it 1700 grains of water from the New River, London, and then sealed it hermetically. The whole weighed 2150$\frac{11}{12}$ grains at the temperature of 32°. It was put for twenty minutes into a freezing mixture of snow and salt till some of it was frozen; it was then, after being wiped first with a dry linen cloth, next with clean washed dry leather, immediately weighed, and found to be $\frac{1}{60}$th of a grain heavier than before. This was repeated exactly in the same manner five different times. At each, more of the water was frozen, and more weight gained When the whole water was frozen, it was $\frac{3}{16}$ths of a grain heavier than it had been when fluid. A thermometer applied to the globe stood at 10°. When allowed to remain till the thermometer rose to 32°, it weighed $\frac{2}{16}$ths of a grain more than it did at the same

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* *Sur les Modif. de l'Atmosph.*

† *Phil. Trans* 1785, part ii.

‡ *Jour. de Phys.* 1785, Oct.

§ *Jour. de Sçavans*, 1785, p. 493.

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temperature when fluid. It will be seen afterwards that ice contains less caloric than water of the same temperature with it. The balance used was nice enough to mark $\frac{1}{1000}$th part of a grain.

This subject had attracted the attention of Lavoisier, a philosopher distinguished by the uncommon accuracy of his researches. His experiments, which were published in the Memoirs of the French Academy for 1783, led him to conclude that the weight of bodies is not altered by heating or cooling them, and consequently that caloric produces no sensible change on the weight of bodies. Count Rumford's experiments on the same subject, which were made about the year 1797, are perfectly decisive. He repeated the experiment of Dr Fordyce with the most scrupulous caution; and, by a number of the most ingenious contrivances, demonstrated, that neither the addition nor the abstraction of caloric, makes any sensible alteration in the weight of bodies *.

6. Caloric not only possesses the velocity of light, but agrees with it also in another property no less peculiar. Its particles are never found cohering together in masses; and whenever they are forcibly accumulated, they fly off in all directions, and separate from each other with inconceivable rapidity. This property necessarily supposes the existence of a mutual repulsion between the particles of caloric.

Thus it appears that caloric and light resemble each other in a great number of properties. Both are emitted from the sun in rays, with the velocity of 200,000 miles in a second; both of them are refracted by transparent bodies, and reflected by polished surfaces; both

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* *Phil. Trans.* 1799, p. 179.

of them consist of particles which mutually repel each other, and which produce no sensible effect upon the weight of other bodies. They differ, however, in this particular: light produces in us the sensation of vision; caloric, on the contrary, the sensation of heat.

Upon the whole, we are authorised by the above statement of facts, to conclude, that the solar light is composed of three distinct substances, in some measure separable by the prism on account of the difference of their refrangibility. The *calorific* rays are the least refrangible, the *deoxidizing* rays are most refrangible, and the *colorific* rays possess a mean degree of refrangibility. Hence the rays in the middle of the spectrum have the greatest illuminating power, those beyond the red end the greatest heating power, and those beyond the violet end the greatest deoxidizing power: and the heating power on the one hand, and the deoxidizing power on the other, gradually encrease as we approach that end of the spectrum where the maximum of each is concentrated. These different bodies resemble each other in so many particulars, that the same reasoning respecting refrangibility, reflexibility, &c. may be applied to all; but they produce different effects upon those bodies on which they act. Little progress has yet been made in the investigation of these effects; but we may look forward to this subject as likely to correct many vague and unmeaning opinions which are at present in vogue among chemists.

SECT. II.

OF THE MOTION OF CALORIC.

FROM the preceding account of the nature of caloric we learn, that it is analagous to light in the rapidity with which it moves when radiated from hot bodies. This rapidity it seems to acquire in all cases, provided its motion be not obstructed by some obstacle. When at perfect liberty, it moves at the rate of 200,000 miles in a second. Such is its velocity when it is emitted from the sun or from burning bodies. But it is capable not only of moving through free space, but also of making its way through all terrestrial bodies whatever. In this respect it differs from all other substances, even from light, which, as far as we know, cannot make its way through all bodies.

Motion of caloric thro' bodies of two kinds:

1. The motion of caloric through bodies is of two kinds: through some bodies it moves with the same rapidity as through free space, or at least its velocity suffers no sensible diminution during its passage. In this way it moves through air, and through several other transparent bodies. Through other bodies it moves with a remarkably slow motion. Thus if we put the point of a bar of iron, twenty inches in length, into a common fire, while a thermometer is attached to the other extremity; four minutes elapse before the thermometer begins to ascend, and 15 minutes by the time it has risen 15°; consequently caloric takes 4′ to pass through a bar of iron 20 inches long. The difference between this

rate and that of 200,000 miles in a second is enormous. The motions must therefore be different in kind.

1. Transmitted; 2. Conducted.

When caloric passes through a body with undiminished velocity, we say that it is *transmitted* through it: on the other hand, when its velocity is prodigiously diminished, as in the case of the iron bar, we say that it is *conducted* through it. It cannot be doubted that caloric is *transmitted* through bodies, and *conducted* through them, in quite a different manner.

Air, and all the transparent bodies hitherto examined, have the property of transmitting caloric through them; though some of them, as glass, do not transmit it till after they have combined with a certain proportion of it: and probably no body transmits it unless a greater quantity enter than is capable of combining with it in the state in which the body is placed. The phenomena of the transmission of caloric are exactly similar to the transmission of light, and admit of precisely the same explanation. What Scheele and several other chemists have called *radiant heat*, is nothing else than transmitted caloric.

Conducting power explained.

2. As the velocity of caloric, when it is *conducted* thro' bodies, is excessively retarded, it is clear that it does not move through them without restraint. It must be detained for some time by the particles of the conducting body, and consequently must be attracted by them. Hence it follows that there is an affinity or attraction between *caloric* and every *conductor*. It is in consequence of this affinity that it is conducted through the body. This perhaps will be better understood by the following illustration:

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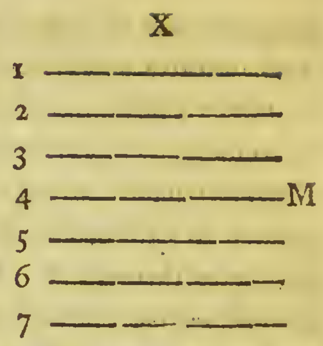

Let M be a body (a mass of iron, for instance) composed of an indefinite number of particles, arranged in the strata 1, 2, 3, 4, 5, 6, 7, &c. Let caloric be communicated to it in the direction X. The first stratum of particles 1 combines with a dose of caloric, and forms a compound which we shall call A. This compound cannot be decomposed by the second stratum, because all the strata before the application of the heat were at the same temperature; consequently the affinity of all for caloric must have been equal. Now it would be absurd to suppose a compound destroyed by an affinity no greater than that which produced it. If therefore only one dose of caloric combined with stratum 1, no caloric could pass beyond that stratum. But the compound A has still an affinity for caloric; it therefore combines with another dose of it, and forms a new compound, which we shall call B.

This stratum is now combined with two doses of caloric; the second of which, according to the general law already explained, is retained by a weaker affinity than the first. Stratum 2, therefore, is capable of abstracting this second dose. Accordingly it combines with it, and forms the compound A. Here are two strata combined each with a dose of caloric, and consequently coustituting compound A. The third stratum is unable to decompose the second, for the same reason that the second was unable to decompose the first while only combined with one dose. Stratum 1 again combines with a dose of caloric, and forms compound B, Stratum 2 is unable to decompose this compound, because being already combined with one dose, its affinity for the second dose cannot be greater than that of stratum 1 for the same second dose.

But stratum 1 combines with a third dose of caloric, and forms a new compound which we shall call C. The affinity of this third dose being inferior to that of the second, stratum 2 abstracts it and forms compound B. This second dose is abstracted from stratum 2 by stratum 3, which now forms compound A. Stratum 1 again forms compound C, to be again decomposed by stratum 2, which stratum forms a new compound B. Compound C is a third time formed by stratum 1. Three strata are now heated. Stratum 1 is combined with three doses, stratum 2 with two doses, and stratum 3 with one dose. The caloric can pass no farther: for stratum 4 cannot decompose compound A, nor stratum 3 compound B, nor stratum 2 compound C. But stratum 1 combines with a fourth dose of caloric, and forms a new compound which we shall call D. This new dose is abstracted by stratum 2, which forms compound C. It is again abstracted from stratum 2 by stratum 3, which forms compound B. From stratum 3 it is abstracted by stratum 4, which forms compound A. Stratum 1 again combines with a new dose, and forms compound D; which is abstracted first by stratum 2, and then by stratum 3, which last stratum forms compound B. Stratum 1 a third time forms compound D; but the dose is immediately abstracted by stratum 2, which forms with it compound C. Compound D is a fourth time formed by stratum 1, and is not decomposed any more. Here are four strata combined with caloric; stratum 1 with four doses, stratum 2 with three doses, stratum 3 with two doses, and stratum 4 with one dose. In this manner may the heating process go on till any number of strata whatever are combined with caloric.

3. Bodies then conduct caloric in consequence of their affinity for it, and the property which they have of combining indefinitely with additional doses of it. Hence the reason of the slowness of the process, or, which is the same thing, of the long time necessary to heat or to cool a body. The process consists in an almost infinite number of repeated compositions and decompositions.

4. We see, too, that when heat is applied to one extremity of a body, the temperature of the strata of that body must diminish equably, according to their distance from the source of heat. Every person must have observed that this is always the case. If, for instance, we pass our hand along an iron rod, one end of which is held in the fire, we shall perceive its temperature gradually diminishing from the end in the fire, which is hottest, to the other extremity, which is coldest.

Has a limit.

5. The passage of caloric through a body, by its conducting power, must have a limit; and that limit depends upon the number of doses of caloric with which the stratum of the body nearest the source of heat is capable of combining. If the length of a body be so great that the strata of which it is composed exceed the number of doses of caloric with which a stratum is capable of combining, it is clear that caloric cannot possibly be conducted through the body; that is to say, the strata farthest distant from the source of heat cannot receive any increase of temperature. This limit depends, in

all cases, upon the quantity of caloric with which a body is capable of combining before it changes its state. All bodies, as far as we know at present, are capable of combining indefinitely with caloric; but the greater number, after the addition of a certain number of doses, change their state. Thus ice, after combining with a certain quantity of caloric, is changed into water, which is converted in its turn to steam by the addition of more caloric. Metals also, when heated to a certain degree, melt, are volatilized, and oxidated: wood and most other combustibles catch fire, and are dissipated. Now whenever as much caloric has combined with the first stratum of a body as it can receive without changing its state, it is evident that no more caloric can enter the body; because the next dose will dissipate the first stratum.

The distance therefore to which a body is capable of conducting caloric is always proportional to the temperature to which that body can be raised before it changes its state. Therefore antimony is capable of conducting caloric farther than wood, and iron farther than antimony, and perhaps stones are capable of conducting it even farther than iron.

6. As bodies conduct caloric in consequence of their affinity for it, and as all bodies have an affinity for caloric, it follows as a consequence, that all bodies must be conductors, unless their conducting power be counteracted by some other property. If a body, for instance, were of such a nature that a single dose of caloric sufficed to produce a change in its state, it is evident that it could not conduct caloric; because every row of particles, as soon as it had combined with a dose of ca-

loric, would change its place, and could not therefore communicate caloric to the strata behind it.

All solids conductors.

7. All *solids* are conductors; because all solids are capable of combining with various doses of caloric before they change their state. This is the case in a very remarkable degree with all earthy and stony bodies; it is the case also with metals, with vegetables, and with animal matters. This, however, must be understood with certain limitations. All bodies are indeed conductors; but they are not conductors in all situations. Most solids are conductors at the common temperature of the atmosphere; but when heated to the temperature at which they change their state, they are no longer conductors. Thus at the temperature of 60° sulphur is a conductor; but when heated to 212°, or the point at which it melts or is volatilized, it is no longer a conductor. In the same manner ice conducts caloric when at the temperature of 20°, or any other degree below the freezing point; but ice at 32° is not a conductor, because the addition of caloric causes it to change its state.

8. With respect to liquids and gaseous bodies, it would appear at first sight that they also are all conductors; for they can be heated as well as solids, and heated too considerably without sensibly changing their state. But fluids differ from solids in one essential particular; their particles are at full liberty to move among themselves, and they obey the smallest impulse: while the particles of solids, from the very nature of these bodies, are fixed and stationary. One of the changes which caloric produces on bodies is expansion, or increase of bulk; and this increase is attended with a proportional diminution of specific gravity. Therefore, whenever

caloric combines with a stratum of particles, the whole stratum becomes specifically lighter than the other particles. This produces no change of situation in solids; but in fluids, if the heated stratum happens to be below the other strata, it is pressed upwards by them, and being at liberty to move, it changes its place, and is buoyed up to the surface of the fluid.

Fluids carry caloric,

In fluids, then, it makes a very great difference to what part of the body the source of heat is applied. If it be applied to the highest stratum of all, or to the surface of the liquid, the caloric can only make its way downwards, as through solids, by the conducting power of the fluid; but if it be applied to the lowest stratum, it makes its way upwards, independent of that conducting power, in consequence of the fluidity of the body and the expansion of the heated particles. The lowest stratum, as soon as it combines with a dose of caloric, becomes specifically lighter, and ascends. New particles approach the source of heat, combine with caloric in their turn, and are displaced. In this manner all the particles come, one after another, to the source of heat; of course the whole of them are heated in a very short time, and the caloric is carried almost at once to much greater distances in fluids than in any solid whatever. Fluids, therefore, have the property of *carrying* or *transporting* caloric; in consequence of which they acquire heat independent altogether of any conducting power.

9. The *carrying* power of fluids was first accurately examined by Count Rumford. This ingenious philosopher was so struck with it the first time he observed it, that he was led to conclude that it is by means of it alone that fluids acquire heat, and that they are alto-

gether destitute of the property of conducting caloric. In a set of experiments on the communication of heat, he made use of thermometers of an uncommon size. Having exposed one of these (the bulb of which was near four inches in diameter) filled with alcohol to as great a heat as it could support, he placed it in a window to cool, where the sun happened to be shining. Some particles of dust had by accident been mixed with the alcohol: these being illuminated by the sun, became perfectly visible, and discovered that the whole liquid in the tube of the thermometer was in a most rapid motion, running swiftly in opposite directions upwards and downwards at the same time. The *ascending* current occupied the axis, the *descending* current the sides of the tube. When the sides of the tube were cooled by means of ice, the velocity of both currents was accelerated. It diminished as the liquid cooled; and when it had acquired the temperature of the room, the motion ceased altogether. This experiment was repeated with linseed oil, and the result was precisely the same. These currents were evidently produced by the particles of the liquid going individually to the sides of the tube, and giving out their caloric. The moment they did so, their specific gravity being increased, they fell to the bottom, and of course pushed up the warmer part of the fluid, which was thus forced to ascend along the axis of the tube. Having reached the top of the tube, the particles gave out part of their caloric, became specifically heavier, and tumbled in their turn to the bottom.

As these internal motions of fluids can only be discovered by mixing with them bodies of the same specific gravity with themselves, and as there is hardly any substance of the same specific gravity with water which is not soluble in it, Count Rumford had recourse to the following ingenious method of ascertaining whether that fluid also followed the same law. The specific gravity of water is increased considerably by dissolving any salt in it; he added, therefore, potass to water till its specific gravity was exactly equal to that of amber, a substance but very little heavier than pure water. A number of small pieces of amber were then mixed with this solution, and the whole put into a glass globe with a long neck, which, on being heated and exposed to cool, exhibited exactly the same phenomena with the other fluids. A change of temperature, amounting only to a very few degrees, was sufficient to set the currents a-flowing; and a motion might at any time be produced by applying a hot or a cold body to any part of the vessel. When a hot body was applied, that part of the fluid nearest it ascended; but it descended on the application of a cold body.

These observations naturally led Count Rumford to examine, whether the heating and cooling of fluids be not very much retarded by every thing which diminishes the fluidity of these bodies. He took a large linseed-oil thermometer with a copper bulb and glass tube: the bulb was placed exactly in the centre of a brass cylinder; so that there was a void space between them all around 0.25175 of an inch thick. The thermometer was kept in its place by means of four wooden pins projecting from the sides and bottom of the cylinder, and by the tube of it passing through the cork stopper of the cylinder. This cylinder was filled with pure water, then held in melting snow till the thermometer fell to 32°, and immediately plunged into a vessel of boiling water. The thermometer rose from 32° to 200° in 597″. It is obvious that all the caloric which served to raise the thermometer must have made its way thro' the water in the cylinder. The experiment was repeated exactly in the same manner; but the water in the cylinder, which amounted to 2276 gr. had 192 gr. of starch boiled in it, which rendered it much less fluid. The thermometer now took 1109″ to rise from 32° to 200°. The same experiment was again repeated with the same quantity of pure water, having 192 gr. of eiderdown mixed with it, which would merely tend to embarrass the motion of the particles. A quantity of stewed apples were also in another experiment put into the cylinder. The following TABLES exhibit the result of all these experiments.

Time the Caloric was in passing into the Thermometer.

Temperature.	Through the Water and Starch.	Through the Water and Eiderdown.	Through stewed Apples.	Through pure Water.
	Seconds.	Seconds.	Seconds.	Seconds.
Therm. rose from 32° to 200° in	1109	949	1096½	597
Therm. rose 80°, *viz.* from 80° to 160°, in	341	269	335	172

Time the Caloric was in passing out of the Thermometer.

Temperature.	Through the Water and Starch.	Through the Water and Eiderdown.	Through stewed Apples.	Through pure Water.
	Seconds.	Seconds.	Seconds.	Seconds.
Therm. fell from 200° to 40° in	1548	1541	1749½	1032
Therm. fell 80°, *viz.* from 160° to 80°, in	468	460	520	277

Now the starch and eiderdown diminished the fluidity of the water. It follows from these experiments, that "the more completely the internal motions of a liquid are impeded, the longer is that liquid before it acquires a given temperature." Therefore, when heat is applied to liquids, they acquire the greatest part of their temperature, in common cases, by their carrying power. If liquids then be conductors, their conducting power is but small when compared with their carrying power.

And conduct it.

All liquids, however, are capable of conducting caloric; for when the source of heat is applied to their surface, the caloric gradually makes its way downwards, and the temperature of every stratum gradually diminishes from the surface to the bottom of the liquid. The increase of temperature in this case is not owing to the carrying power of the liquid. By that power caloric may indeed make its way upwards through liquids, but certainly not downwards. Liquids, then, are conductors of caloric.

Count Rumford, indeed, has drawn a different conclusion from his experiments. He fixed a cake of ice in the bottom of a glass jar, covered $\frac{1}{4}$ inch thick with cold water. Over this was poured gently a considerable quantity of boiling water. Now, if water were a non-conductor, no caloric would pass through the cold water, and consequently none of the ice would be melted. The melting of the ice, then, was to determine whether water be a conductor or not. In two hours about half of the ice was melted. This one would think, at first sight, a decisive proof that water is a conductor. But the Count has fallen upon a very ingenious method of accounting for the melting of the ice, " without being under the necessity (as he tells us) of renouncing his theory, that fluids are non-conductors."

It is well known that the specific gravity of water about 40° is a maximum: if it be either heated above 40°, or cooled down below 40°, its density diminishes. Therefore, whenever a particle of water arrives at the temperature of 40°, it will sink to the bottom of the vessel. Now as the water next the ice was at 32°, it is evident that whenever any part of the hot water was cooled down to 40°, it would sink, displace the water at 32°, come into contact with the ice, and of course melt it. The Count's ingenuity, never without resources, enabled him to prove completely that the ice employed in his experiment was actually melted in that manner: for when he covered the ice partially with slips of wood, that part which was shaded by the wood was not melted; and when he covered the whole of the ice with a thin plate of tin, having a circular hole in the middle, only the part exactly under the hole was melted. From these facts it certainly may be concluded that the ice was melted by descending currents of water.

But the point to be proved is, not whether there were descending currents, but whether water be a conductor or not. Now if water be a non-conductor, I ask, How the hot water was cooled down to 40°? Not at the surface; for the Count himself tells us, that there the temperature was never under 108°: not by the sides of the vessel; for the descending current in one experiment was exactly in the axis: and it follows irresistibly, from the experiment with the slips of wood, that these descending currents fell equally upon every part of the surface of the ice; which would have been impossible if these currents had been cooled by the side of the vessel. The hot water, then, must have been cooled down to 40° by the cold water below it; consequently it must have imparted caloric to this cold water. If so, one particle of water is capable of absorbing caloric from another; that is, water is a *conductor of caloric*. After the hot water had stood an hour over the ice, its temperature was as follows:

At the surface of the ice	40°
One inch above the ice	80
Two inches	118
Three inches	128
Four inches	130
Seven inches	131

How is it possible to account for this gradual diminution of heat as we approach the ice if water be a non-conductor? The water, it may be said, gives out caloric at its surface, falls down, and arranges itself according to its specific gravity. If so, how comes it that there is only one degree of difference between the temperature at 4 and at 7 inches above the ice? Thus it appears that the Count's experiment, instead of demonstrating that water is a non-conductor, rather favours the supposition that it is a conductor.

The Count tried whether oil and mercury be conductors in the following manner: When water is frozen in a glass jar by means of a freezing mixture, he observed, that the ice first begins to be formed at the sides, and gradually increases in thickness; and that the water on the axis of the vessel, which retains its fluidity longest, being compressed by the expansion of the ice, is forced upwards, and when completely frozen forms a pointed projection or nipple, which is sometimes half an inch higher than the rest of the ice. Upon ice frozen in this manner he poured olive oil, previously cooled down to 32°, till it stood at the height of three inches above the ice. The vessel was surrounded as high as the ice with a mixture of pounded ice and water. A solid cylinder of wrought iron, 1.25 inch in diameter, and 12 inches long, provided with a hollow cylindrical sheath of thick paper, was heated to the temperature of 210° in boiling water; and being suddenly introduced into its sheath, was suspended from the ceiling of the room, and very gradually let down into the oil, until the middle of the flat surface of the hot iron, which was directly above the point of conical projection of the ice, was distant from it only $\frac{2}{10}$ of an inch. The end of the sheath descended $\frac{1}{10}$ of an inch lower than the end of the hot metallic cylinder. Now it is evident that if olive oil be a conductor, caloric must pass down through it from the iron and melt the ice. None of the ice, however, was melted; and when mercury was substituted for oil, the result was just the same *.

From this experiment the Count concluded, that neither oil nor mercury are capable of conducting caloric. But it is by no means sufficiently delicate to decide the point. If a thermometer be substituted instead of the nipple of ice, it always rises several degrees, as I have ascertained by experiment; consequently caloric passes downwards even in this case. The experiment, then, is in fact favourable to the supposition that these fluids are conductors.

Count Rumford's experiments then do not prove his position that fluids are non-conductors, but rather the contrary. That they are all in fact conductors of caloric, I ascertained in the following manner: The liquid whose conducting power was to be examined was poured into a glass vessel till it filled it about half way; then a hot liquid of a less specific gravity was poured over it. Thermometers were placed at the surface, in the centre, and at the bottom of the cold liquid; if these rose, it followed that the liquid was a conductor, because the caloric made its way downwards. For instance, to examine the conducting power of mercury, a glass jar was half filled with that liquid metal, and boiling water then poured over it. The thermometer at the surface began immediately to rise, then the thermometer at the centre, and lastly that at the bottom. The first rose to 118°, the second to 90°, the third to 86°: the first reached its maximum in 1′, the second in 15′, the third in 25′. The conducting power of wa-

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* Rumford, Essay vii. Part ii. chap. i.

ter was tried in the same manner, only hot oil was poured over it. A variety of precautions were necessary to ensure accuracy; but for these I refer to the experiments themselves, which are detailed in Nicholson's Journal*.

These experiments have been since confirmed by a very ingeniously contrived and convincing experiment made by Mr Murray. To prevent the possibility of any heat being conducted by the vessel, he employed a vessel of ice, which is incapable of conducting any degree of heat greater than 32°. In this vessel he made experiments of the same nature with those that I have just mentioned, and the result was the same. The thermometer constantly rose upon the application of a hot body to the surface of the liquid in which the thermometer was standing†. Mr Dalton has likewise published lately a set of experiments almost exactly of the same nature with mine, and with the same result. From the date affixed to his paper we learn, that his experiments had been made, and an account of them read to the Manchester Society just about the same time that I was drawing up an account of mine; though they were not published till about two years after ‡.

Fluids, then, as far as experiments have been made, are conductors of caloric as well as solids. Hence it follows that all bodies with which we are acquainted are capable of conducting caloric.

Relative conducting powers of bodies.

If we take a bar of iron and a piece of stone of equal dimensions, and putting one end of each into the fire,

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* Nicholson's *Journal*, iv. 529.

† Ibid. 8vo, I.

‡ *Manchester Memoirs*, v.

apply either thermometers or our hands to the other, we shall find the extremity of the iron sensibly hot long before that of the stone. Caloric therefore is not conducted through all bodies with the same celerity and ease. Those that allow it to pass with facility, are called *good conductors;* those through which it passes with difficulty, are called *bad conductors.*

The experiments hitherto made on this subject are too few to enable us to determine with precision the rate at which different bodies conduct caloric. The subject, however, is of the highest importance, and deserves a thorough investigation.

Of metals,

Metals are the best conductors of caloric of all the solids hitherto examined. The conducting powers of all, however, are not equal. Dr Ingenhousz procured cylinders of several metals exactly of the same size, and having coated them with wax, he plunged their ends into hot water, and judged of the conducting power of each by the length of wax-coating melted. From these experiments he concluded, that the conducting powers of the metals which he examined were in the following order*.

Silver,
Gold,
Copper, } nearly equal,
Tin,
Platinum,
Iron,
Steel, } much inferior to the others.
Lead,

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* *Jour. de Phys.* 1789, p. 68.

Stones,

Next to metals, stones seem to be the best conductors; but this property varies considerably in different stones. Bricks are much worse conductors than most stones.

Glass,

Glass seems not to differ much from stones in its conducting power. Like them, it is a bad conductor. This is the reason that it is so apt to crack on being suddenly heated or cooled. One part of it, receiving or parting with its caloric before the rest, expands or contracts, and destroys the cohesion.

Woods,

Next to these come dried woods. Mr Meyer* has made a set of experiments on the conducting power of a considerable number of woods. The result may be seen in the following TABLE, in which the conducting power of water is supposed = 1.

Bodies.	Conducting Power.
Water	= 1.00
Diaspyrus ebenum	= 2.17
Pyrus malus	= 2.74
Fraxinus excelsior	= 3.08
Fagus sylvatica	= 3.21
Carpinus betulus	= 3.23
Prunus domestica	= 3.25
Ulmus	= 3.25
Quercus robur pedunculata . . .	= 3 26
Pyrus communis	= 3.32
Betula alba	= 3.41
Quercus robur sessilis	= 3.63
Pinus picea	= 3.75

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* *Ann. de Chim.* xxx. 32.

Bodies.	Conducting Power.
Betula alnus	= 3.84
Pinus sylvestris	= 3.86
Pinus abies	= 3.89
Tilea Europæa	= 3.90

Charcoal, feathers, &c.

Charcoal is also a bad conductor: According to the experiments of Morveau, its conducting power is to that of fine sand : : 2 : 3*. Feathers, silk, wool, and hair, are still worse conductors than any of the substances yet mentioned. This is the reason that they answer well for articles of clothing. They do not allow the heat of the body to be carried off by the cold external air. Count Rumford has made a very ingenious set of experiments on the conducting power of these substances †. He ascertained that their conducting power is inversely as the fineness of their texture.

Relative conducting powers of liquids.

The conducting power of liquid bodies has not been examined with any degree of precision. I find, by experiment, that the relative conducting powers of mercury, water, and linseed oil, are as follows:

I. EQUAL BULKS.

Water	= 1
Mercury	= 2
Linseed oil	= 1.111

II. EQUAL WEIGHTS.

Water	= 1
Mercury	= 4.8
Linseed oil	= 1.085

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[*] *Ann. de Chim.* xxvi. 225.

[†] *Phil. Trans.* 1792.

As bodies conduct caloric in consequence of their affinity for it, the inequality of their conducing power is a demonstration that their affinities for caloric are also unequal. It is probable that their affinity for caloric is in all cases the inverse of their conducting power. If therefore we were in possession of the relative conducting powers of bodies, the inverse of that would give us the affinities in absolute numbers. Thus the affinity of

Water is . . . . = 1 . . . = 1
Mercury . . . . = $\frac{1}{4.8}$ . . = 0.208
Linseed oil . . . = $\frac{1}{1.085}$. = 0.921

SECT. III.

OF THE EQUAL DISTRIBUTION OF TEMPERATURE.

WE have seen, in the preceding Section, that caloric is capable of moving through all bodies, though with different degrees of facility. The consequence of this property is a tendency which it has to distribute itself among all contiguous bodies in such a manner, that the thermometer indicates the same temperature in all.

Contiguous bodies assume the same temperature.

1. We can easily increase the temperature of bodies, whenever we choose, by exposing them to the action of our artificial fires. Thus a bar of iron may be made red hot by keeping it a sufficient time in a common fire: but if we take it from the fire, and expose it to the open air, it does not retain the heat which it had received; but becomes gradually colder and colder, till

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it arrives at the temperature of the bodies in its neighbourhood. On the other hand, if we cool down the iron bar, by keeping it for some time covered with snow, and then carry it into a warm room, it does not retain its low temperature, but becomes gradually hotter, till it acquires the temperature of the room. Thus it appears that no body can retain its high temperature while surrounded by colder bodies, nor its low temperature while it is surrounded by hotter bodies. The caloric, however combined at first, gradually distributes itself in such a manner, that all contiguous bodies, when examined by the thermometer, indicate the same temperature. These changes occupy a longer or a shorter time, according to the size or the nature of the body; but they always take place at last.

This law is familiar to every person. When we wish to heat any thing, we carry it towards the fire; when we wish to cool it, we surround it by cold bodies. The caloric in this last case is not lost, it is merely distributed equally through the bodies. When a number of substances are mixed together, some of them cold and some of them hot, they all acquire the same temperature; and this new temperature is a mean of all the first temperatures of the substances. Those which were hot become colder, and those which were cold become hotter. This property of caloric has been called by philosophers the *equilibrium of caloric;* but it might, with greater propriety, be denominated, the *equal distribution of temperature.*

2. The caloric which leaves hot bodies, in order to produce this equality of temperature, is partly *conducted* by means of the neighbouring bodies, and partly *radiates* from the surface of the hot body.

That it is conducted by means of the neighbouring bodies is obvious from this circumstance, that the rate of cooling of hot bodies depends very much upon the nature of the cold bodies which surrounds them. A hot iron, suspended in the air, is much longer in cooling than it would be if plunged into water of the same temperature with the air.

Heat radiated from hot bodies,

3. That caloric is radiated from the surfaces of bodies, follows irresistibly from the experiments detailed in the first Section of this Chapter. This must therefore be one cause of their cooling; but what proportion the caloric radiated from bodies, bears to that conducted from them, remains to be ascertained by subsequent experiments.

And conducted from them.

4. That radiation is not the sole cause of the cooling of hot bodies, has been ascertained by the experiments of Mr Pictet *, who demonstrated, that hot bodies cool more slowly when suspended in the vacuum of an air pump than when in the open air; and by those of Count Rumford †, who proved that the rate of cooling is still more slow in the torricellian vacuum. Now placing a body in a vacuum cannot diminish the radiation of caloric from it; though it must prevent the usual quantity of caloric from being conducted away.

Law of the heating and cooling of bodies.

5. From the experiments of Kraft and Richmann ‡, made with much precision, and upon a great number of bodies, the following general conclusion has been drawn, which comprehends all that is known at present respecting the heating and cooling of bodies.

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* *Sur le Feu*, chap. i.

† *Phil. Trans.* 1786.

‡ *Nov. Comm. Petrop.* i. 195.

"When a body is suspended in a medium of a temperature different from its own, the difference between the temperature of the body and the medium diminishes in a geometrical ratio, while the time increases in an arithmetical ratio." This law had been first suggested by Sir Isaac Newton, who calculated by means of it several temperatures above the scale of thermometers.

6. The cooling of hot bodies depends also very much upon their goodness as conductors of heat. Bad conductors cool much more slowly than good conductors. When mercury and water, each heated to the same degree, are placed in the same circumstances, the mercury cools more than twice as fast as the water. In general, other things being the same, the rate of cooling may be considered as nearly inversely as the conducting power of fluids.

Attempts to explain the equilibrium of heat.

7. As soon as it was discovered that contiguous bodies assume the same temperature, various attempts were made by philosophers to account for the fact. De Mairan, and other writers in the earlier part of the 18th century, explained it, by supposing that caloric is a fluid which pervades all space, and that bodies merely float in it as a sponge does in water, without having any affinity for it whatever. The consequence of all this was a constant tendency to an equality of density. Of course, if too much caloric is accumulated in one body, it must flow out; if too little, it must flow in till the equality of density be restored.

This hypothesis is inconsistent with the phenomena which it is intended to explain. Were it true, all bodies ought to heat and to cool with the same facility; and the heat ought to continue as long in the focus of a burning glass as in a globe of gold of the same diameter. It is equally inconsistent with the nature of caloric; which has been shewn, in the first Section of this Chapter, to be a body very different from the hypothetical fluid of De Mairan.

Hypothesis of Pictet,

8. Another explanation of the equal distribution of temperature, and a much more ingenious one, was proposed by Mr Pictet. According to this philosopher, when caloric is accumulated in any body, the repulsion between its particles is increased, because the distance between them is diminished. Accordingly they repel each other; and this causes them to fly off in every direction, and to continue to separate till they are opposed by caloric in other bodies of the same relative density with themselves, which, by repelling them in its turn, compels them to continue where they are. The equal distribution of temperature therefore depends on the balancing of two opposite forces: the repulsion between the particles of caloric in the body, which tends to diminish the temperature; and the repulsion between the caloric of the body and the surrounding caloric, which tends to raise the temperature. When the first force is greater than the second, as is the case when the temperature of a body is higher than that of the surrounding bodies, the caloric flies off, and the body becomes colder. When the last force is stronger than the first, as is the case when a body is colder than those which are around it, the particles of its caloric are obliged to approach nearer each other, new caloric enters to occupy the space which they had left, and the body becomes hotter. When the two forces are equal, the bodies are said to be of the same temperature, and no change takes place*.

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* See Pictet, *sur le Feu*, chap. i.

But this theory, notwithstanding its ingenuity, is inconsistent with the phenomena of the heating and cooling of bodies, and has accordingly been abandoned by the ingenious author himself.

Of Prevost.

9. The opinion at present most generally received, and which accounts for the phenomena in the most satisfactory manner, is that of Prevost, first published in the *Journal de Physique* for 1791, in an essay on *the equilibrium of caloric;* and afterwards detailed at greater length in his *Recherches sur la Chaleur**. It was soon after adopted by Mr Pictet†, and has been lately applied by Prevost with much address to the experiments of Herschel and Pictet‡. According to him, caloric is a *discrete* fluid, each particle of which moves with enormous velocity when in a state of liberty. Hot bodies emit calorific rays in all directions; but its particles are at such a distance from each other, that various currents may cross each other without disturbing one another, as is the case with light. The consequence of this must be, that if we suppose two neighbouring spaces in which caloric abounds, there must be a continual exchange of caloric between these two spaces. If it abounds equally in each, the interchanges will balance each other, and the temperature will continue the same. If one contains more than the other, the exchanges must be unequal; and by a continual repetition of this inequality, the equilibrium of temperature must be restored between them.

If we suppose a body placed in a medium hotter than itself, and the temperature of that medium constant, we

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* Geneva, 1792. † *Biblioth. Britan.* iv. 30.

‡ *Phil. Trans.* 1802, p. 403.

may consider the caloric of the medium as consisting of two parts; one equal to that of the body, the other equal to the difference between the temperature of the two. The first part may be left out of view, as its radiations will be counterbalanced by those of the body. The excess alone requires consideration; and relatively to that excess the body is absolutely cold, or contains no caloric whatever. If we suppose that in one second the body receives $\frac{1}{10}$th of this excess, at the end of the first second the excess will be only $\frac{9}{10}$ths. One tenth of this excess will pass into the body during the next second, and the excess will be reduced to $\frac{9}{10}$ of $\frac{9}{10}$, or $(\frac{9}{10})^2$. At the end of the third second, the excess will be $(\frac{9}{10})^3$; at the end of the fourth, $(\frac{9}{10})^4$; and so on: the time increasing in an arithmetical ratio, while the excess diminishes in a geometrical ratio, according to Richmann's rule.

Such is a sketch of Prevost's theory. It is founded altogether upon the radiation of caloric, and leaves the effect of the conducting power of bodies out of sight. The reality of the radiation cannot be doubted; and it is exceedingly probable that the equal distribution of temperature is the consequence of it. Were caloric merely conducted, its progress would be excessively slow, and indeed absolute equality of temperature would scarcely ever take place. At the same time, it must be allowed that this property of bodies has very considerable influence in regulating the time which elapses before the temperature of contiguous bodies is brought to equality; and in so far as Mr Prevost's hypothesis overlooks this circumstance, which obviously depends upon the affinity existing between caloric and other bodies, it must be considered as imperfect.

SECT. IV.

OF THE EFFECTS OF CALORIC.

HAVING in the preceding Sections considered the nature of caloric, the manner in which it moves through other bodies, and distributes itself among them; let us now examine, in the next place, the effects which it produces upon other bodies, either by entering into them or separating from them. The knowledge of these effects we shall find of the greatest importance, both on account of the immense additional power which it puts into our possession, and of the facility with which it enables us to comprehend and explain many of the most important phenomena of nature. The effects which caloric produces on bodies may be arranged under three heads, namely, 1. Changes in bulk; 2. Changes in state; and, 3. Changes in combination. Let us consider these three sets of Changes in their order.

I. OF CHANGES IN BULK.

Expansion

IT may be laid down as a general rule to which there is no known exception, that every addition or abstraction of caloric makes a corresponding change in the bulk of the body which has been subjected to this alteration in the quantity of its heat. In general, the addition of heat encreases the bulk of a body, and the abstraction of it diminishes its bulk; but this is not uniformly the case, though the exceptions are not numerous. Indeed these exceptions are not only confined to a very small number of bodies, but even in them they do not hold, except at certain particular temperatures; while at all other temperatures these bodies are increased in bulk when heated, and diminished in bulk by being cooled. We may therefore consider *expansion* as one of the most general effects of heat. It is certainly one of the most important, as it has furnished us with the means of measuring all the others. Let us, in the first place, consider the phenomena of expansion, and then turn our attention to the exceptions which have been observed.

Differs in different bodies.

1. Though all bodies are expanded by heat and contracted by cold, and this expansion in the same body is always proportional to some function of the quantity of caloric added or abstracted; yet the absolute expansion, or contraction, has been found to differ exceedingly in different bodies. In general, the expansion of gaseous bodies is greatest of all; that of liquids is much smaller, and that of solids the smallest of all. Thus, 100 cubic inches of atmospheric air, by being heated from the temperature of 32° to that of 212°, are encreased to 137.5 cubic inches; while the same augmentation of temperature only makes 100 cubic inches of water assume the bulk of 104.5 cubic inches: and 100 cubic inches of iron, when heated from 32° to 212°, assume a bulk scarcely exceeding 100.1 cubic inches. From this example, we see that the expansion of air is more than 8 times greater than that of water: and the expansion of water about 45 times greater than that of iron.

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Expansion of gases,

2. An accurate knowledge of the expansion of gaseous bodies being frequently of great importance in chemical researches, many experiments have been made to ascertain it; yet, till lately, the problem was unsolved. The results of philosophers were so various and discordant, that it was impossible to form any opinion on the subject. This was owing to the want of sufficient care in excluding water from the vessels in which the expansion of the gases was measured. The heat which was applied converted portions of this water into vapour, which, mixing with the gas, totally disguised the real changes in bulk which it had undergone. To this circumstance we are to ascribe the difference in the determinations of Deluc, General Roy, Saussure, Divernois, &c. Fortunately the problem has lately engaged the attention of two very ingenious and precise philosophers; and their experiments, made with the proper precautions, have solved the problem. The experiments of Mr Dalton of Manchester were read to the philosophical society of Manchester in October 1801, and published early in 1802 *. To him therefore the honour of the discovery of the law of the dilitation of gaseous bodies is due: for Mr Gay Lussac did not publish his dissertation on the expansion of the gases † till more than ſix months after. Mr Dalton's experiments are distinguished by a simplicity of apparatus which adds greatly to their value, as it puts it in the power of others to repeat them without difficulty. It consists merely of a glass tube, open at one end, and divided into equal parts; the gas to be examined was introduced into it

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* *Manchester Memoires*, v. 593.

† *Ann. de Chim.* xliii. 137.

after being properly dried, and the tube is filled with mercury at the open end to a given point; heat is then applied, and the dilatation is observed by the quantity of mercury which is pushed out. Mr Gay Lussac's apparatus is more complicated but equally precise; and as his experiments were made on larger bulks of air, their coincidence with those of Mr Dalton adds considerably to the confidence which may be placed in the results.

The same in all,

From the experiments of these philosophers it follows, that all gaseous bodies whatever undergo the *same* expansion by the same addition of heat, supposing them placed in the same circumstances. It is sufficient, then, to ascertain the law of expansion observed by any one gaseous body, in order to know the exact rate of dilatation of them all. Now, from the experiments of Gay Lussac we learn, that air, by being heated from 32° to 212°, expands from 100 to 137.5 parts: the increase of bulk for 180° is then 37.5 parts; or, supposing the bulk at 32° to be unity, the increase is equal to 0.375 parts: this gives us 0.00208, or $\frac{1}{480}$th part, for the expansion of air for 1° of the thermometer. Mr Dalton found, that 100 parts of air, by being heated from 55° to 212°, expanded to 132.5 parts: this gives us an expansion of 0.00207, or $\frac{1}{483}$ part, for 1°; which differs as little from the determination of Lussac as can be expected in experiments of such delicacy.

And nearly equable.

From the experiments of Mr Dalton, it appears that the expansion of air is almost perfectly equable; that is to say, that the same increase of bulk takes place by the same addition of caloric at all different temperatures. It is true, indeed, that the rate of diminution appears to diminish as the temperature increases. Thus the expansion from 55° to 133°½, or for the first 77½ degrees, was 167 parts; while the expansion from 133½ to 212°, or for the next 77°½, was only 158 parts, or 9 parts less than the first. But this difference, in all likelihood, is chiefly apparent; for Deluc has demonstrated, that the thermometer is not an accurate measure of the increase of heat.

From the experiments of Gay Lussac, it appears that the steam of water, and the vapour of ether, undergo the same dilation with air when the same addition is made to their temperature. We may conclude, then, that all elastic fluids expand equally and uniformly by heat; and that this expansion is nearly equable, though not perfectly so. The following TABLE gives us the bulk of a given quantity of air at all temperatures from 32° to 212°.

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Expansion of air.

Temp.	Bulk.	Temp.	Bulk.	Temp.	Bulk.
32°	100000	59°	105616	86°	111232
33	100208	60	105824	87	111440
34	100416	61	106032	88	111648
35	100624	62	106240	89	111856
36	100832	63	106448	90	112064
37	101040	64	106656	91	112272
38	101248	65	106864	92	112486
39	101456	66	107070	93	112688
40	101664	67	107280	94	112896
41	101872	68	107488	95	113104
42	102080	69	107696	96	113312
43	102288	70	107904	97	113520
44	102496	71	108112	98	113728
45	102764	72	108320	99	113936
46	102912	73	108528	100	114144
47	103120	74	108736	110	116224
48	103328	75	108944	120	118304
49	103536	76	109152	130	120384
50	103744	77	109360	140	122464
51	103952	78	109568	150	144544
52	104160	79	109776	160	126624
53	104268	80	109984	170	128704
54	104576	81	110192	180	130784
55	104784	82	110400	190	132864
56	104992	83	110608	200	134944
57	105220	84	110816	210	137024
58	105408	85	111024	212	137440

Expansion of liquids,

3. The expansion of liquid bodies differs from that of the elastic fluids, not only in quantity, but in the want of uniformity with which they expand when equal additions are made to the temperature of each. This difference seems to depend upon the fixity or volatility of the component parts of the liquid bodies; for in general those liquids expand most by a given addition of heat, whose boiling temperatures are lowest, or which

Not uniform.

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contain in them an ingredient which readily assumes the gaseous form. Thus mercury expands much less when heated to a given temperature than water, which boils at a heat much inferior to mercury; and alcohol is much more expanded than water, because its boiling temperature is lower. In like manner, nitric acid is much more expanded than sulphuric acid; not only because its boiling point is lower, but because a portion of it has a tendency to assume the form of an elastic fluid. This rule holds at least in all the liquids whose expansion I have hitherto tried. We may consider it therefore as a pretty general fact, that the higher the temperature necessary to cause a liquid to boil, the smaller the expansion is which is produced by the addition of a degree of heat; or, in other words, the expansibility of liquids is nearly inversely as their boiling temperature *.

Increases with the temperature.

4. Another circumstance respecting the expansion of liquids deserves particular attention: The expansibility of every one seems to increase with the temperature; or, in other words, the nearer a liquid is to the temperature at which it boils, the greater is the expansion produced by the addition of a degree of caloric: and, on the other hand, the farther it is from the boiling temperature, the smaller is the increase of bulk produced by the addition of a degree of caloric. Hence it happens, that the expansion of those liquids approaches

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* Mr Dalton has lately suggested it as probable, that the expansion of all liquids from their freezing to their boiling temperatures is the same constant quantity. This circumstance did not strike me in a set of experiments which I lately made on the expansion of liquids. If it prove accurate, it will greatly simplify our notions concerning expansion by heat.

nearest to equability whose boiling temperatures are highest; or, to speak more precisely, the ratio of the expansibility increases the more slowly the higher the boiling temperature is[†].

Not connected with their density.

5. These observations are sufficient to show us, that the expansion of liquids is altogether unconnected with their density. It depends upon the quantity of heat necessary to cause them to boil, and to convert them into elastic fluids. But we are altogether ignorant at present of the reason why different liquids require different temperatures to produce this change.

6. The following TABLE will give the reader a precise notion of the rate of expansion of those liquids which have been hitherto examined by chemical philosophers.

[†] This fact, which holds in all the liquids which I have examined, coincides very exactly with Mr Dalton's opinion just mentioned.

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Table of expansions.

Temp.	Mercury *.	Linseed Oil †.	Sulphuric Acid ‡.	Nitric Acid ‡.	Water §.	Oil of Turpen. ‡	Alcohol §.
32°	100000	100000	—	—	—	—	100000
40	100081	—	99752	99514	—	—	100539
50	100183	—	100000	100000	100023	100000	101105
60	100304	—	100279	100486	100091	100460	101688
70	100406	—	100558	100990	100197	100993	102281
80	100508	—	100806	101530	100332	101471	102890
90	100610	—	101054	102088	100694	101931	103517
100	100712	102760	101317	102620	100908	102446	104162
110	100813	—	101540	103196	—	102943	—
120	100915	—	101834	103776	101404	103421	—
130	101017	—	102097	104352	—	103954	—
140	101119	—	102320	105132	—	104573	—
150	101220	—	102614	—	102017	—	—
160	101322	—	102893	—	—	—	—
170	101424	—	103116	—	—	—	—
180	101526	—	103339	—	—	—	—
190	101628	—	103587	—	103617	—	—
200	101730	—	103911	—	—	—	—
212	101835	107250	—	—	104577	—	—

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* This is only an approximation to accuracy. Mr Deluc has shewn, that the expansion of mercury from 32° to 122° is to its expansion from 122° to the temperature of boiling water as 14 to 15.

† The expansion of linseed oil was determined by Sir Isaac Newton.

‡ The expansion of these three liquids is given from my experiments. They were made by filling thermometers with the liquids, and noting down the degrees at which the liquids stood at the different temperatures marked. The weight of liquid equivalent to one degree of the tube was then ascertained, and the weight of the whole liquid whose expansion was tried. From these data, it was easy to ascertain the rate of expansion. The degrees were marked corresponding to a good mercurial thermometer. But as the expansion of mercury is not equable, it is obvious that the numbers gradually deviate from accuracy in proportion to the temperature. It was the consciousness of this that induced me to omit the higher parts of the scale altogether.

§ The expansion of these liquids was ascertained by Sir Charles Blag-

Expansion of solids.

7. The expansion of solid bodies is so small, that a micrometer is necessary to detect the encrease of bulk. As far as is known, the expansion is equable, at least the deviation from perfect equality is insensible. The following Table exhibits the expansion of most of the solids which have been hitherto examined. Most of the experiments were made by Smeaton.

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den and Mr Gilpin. My experiments give the expansion of both considerably less. Thus I found the expansion of water as follows:

Temp.	Expansion.	Temp.	Expansion.
42.5°	100000	112.5°	100777
52.5	100030	122.5	101006
62.5	100106	132.5	101220
72.5	100182	142.5	101495
82.5	100273	152.5	101755
92.5	100471	162.5	102040
102.5	100624	172.5	102260

Mr Deluc, by mixing together equal quantities of water at 32° and boiling water, ascertained the medium temperature between that of boiling and freezing water. Suppose the whole expansion from the temperature of freezing water to that of boiling water to be divided into 80 parts; he found that the expansion from 32° to that medium temperature (which would be 122°, if the expansion of mercury were equable), and from that temperature to that of boiling water, in different liquids, to be as follows:

	From 32° to M. Temp.	From M. Temp. to boiling Water.	Ratios.
Mercury	38.6	41.4	14 : 15
Olive and linseed oil	37.8	42.2	13.4 : 15
Oil of camomile	37.2	42.8	13 : 15
Water saturated with salt	34.9	45.1	11.6 : 15
Rectified spirit of wine	33.7	46.3	10.9 : 15
Water	19.2	60.8	4.7 : 15

Temperature.	Platinum †	Antimony.	Steel.	Iron.	Cast Iron.	Bismuth.
32°	120000	120000	120000	120000	120000	120000
212	120104	120130	120147	120151		120167
White heat *			123428	121500	122571	

	Copper.	Cast Brass.	Brass Wire.	Tin.	Lead.	Zinc.
32°	120000	120000	120000	120000	120000	120000
212	120204	120225	120232	120298	120344	120355

	Hammered zinc.	Zinc 8 Tin 1	Lead 2 Tin 1	Brass 2 Zinc 1	Pewter.	Copper 3 Tin ‡ 1
32°	120000	120000	120000	120000	120000	120000
212	120373	120323	120301	120247	120274	120218

Expansion of glass.

The expansion of glass is a point of great importance, as it influences the result of most experiments on temperature. It has been examined with much precision by Mr Deluc. The rate of its expansion, as settled by that philosopher, may be seen in the following Table :

Temp.	Bulk.	Temp.	Bulk.	Temp.	Bulk.
32°	100000	100°	100023	167°	100056
50	100006	120	100033	190	100069
70	100014	150	100044	212	100083

From this Table, it appears, that when glass is heat-

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* Rinman.

† Borda.

‡ The metal whose expansion is here given was an alloy composed of three parts of copper and one of tin. The figures in some of the preceding columns are to be understood in the same manner. Thus in the last column but two, the metal consisted of two parts of brass alloyed with one of zinc.

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ed one degree, it undergoes an expansion which amounts nearly to $\frac{1}{100000}$ of the whole bulk *.

Nature of the thermometer.

8. The property which bodies possess of expanding, when heat is applied to them, has furnished us with an instrument for measuring the relative temperatures of bodies. This instrument is the *thermometer*. A thermometer is merely a hollow tube of glass, hermetically sealed, and blown at one end into a hollow globe or *bulb*. The bulb and part of the tube are filled with mercury. When the bulb is plunged into a hot body, the mercury expands, and of course *rises* in the tube; but when it is plunged into a cold body, the mercury contracts, and of course *falls* in the tube. The rising of the mercury indicates an increase of heat; its falling a diminution of it; and the quantity which it rises and falls indicates the proportion of increase or diminution. To facilitate observation, the tube is divided into a number of equal parts called degrees.

The thermometer, to which we are indebted for almost all the knowledge respecting caloric which we possess, was invented about the beginning of the 17th century; and is supposed by some to have been first thought of by Sanctorio, the celebrated founder of statical medicine. The first rude thermometer was improved by the Florentine academicians and by Mr Boyle; but it was Sir Isaac Newton who rendered it really useful, by pointing out the method of constructing thermometers capable of being compared together.

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* On the supposition that metals expand equably, the expansion of a mass of metal, by being heated a given number of degrees, is as follows: Let $a =$ the expansion of the mass in length for 1°, which must be found by experiment; $b =$ the number of degrees whose expansion is required; $s =$ the solid contents of the metallic mass; $x =$ the expansion sought; then $x = 3\,b\,a\,s$.

How graduated.

If we plunge a thermometer ever so often into melting snow, it will always stand at the same point. Hence we learn that snow always begins to melt at the same temperature. Dr Hooke observed also, that if we plunge a thermometer ever so often into boiling water, it always stands at the same point, provided the pressure of the atmosphere be the same; consequently water (other things being the same) always boils at the same temperature. If therefore we plunge a new made thermometer into melting snow, and mark the point at which the mercury stands in the tube ; then plunge it into boiling water, and mark the new point at which the mercury stands; then divide the portion of the tube between the two marks into any number of equal parts; suppose 100, calling the freezing point 0, and the boiling point 100 ; every other thermometer constructed in a similar manner will stand at the same degree with the first thermometer, when both are applied to a body of the same temperature. All such thermometers therefore may be compared together, and the scale may be extended to any length both above the boiling point and below the freezing point.

Newton first pointed out the method of making comparable thermometers[*] ; but the practical part of the art was greatly simplified by Mr Fahrenheit of Amsterdam and Dr Martine of St Andrew's[†]. Mercury is the liquid which answers best for thermometers, because its expansion is most equable, owing to the great distance between its boiling and freezing points. There

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[*] *Phil. Trans.* Abr. iv. 1.

[†] *On the Construction and Graduation of Thermometers.*

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Different thermometers used.

are four different thermometers used at present in Europe, differing from one another in the number of degrees into which the space between the freezing and boiling points is divided. These are Fahrenheit's, Celsius's, Reaumur's, and De Lisle's.

Fahrenheit's thermometer is used in Britain. The space between the boiling and freezing points is divided into 180°; but the scale begins at the temperature produced by mixing together snow and common salt, which is 32° below the freezing point; of course the freezing point is marked 32°, and the boiling point 212°[*].

The thermometer of Celsius is used in Sweden; it has been used also in France since the Revolution under the name of the *thermometre centigrade*. In it the space between the freezing and boiling points is divided into 100°. The freezing point is marked 0, the boiling point 100°[†].

The thermometer known by the name of Reaumur, which was in fact constructed by De Luc, was used in France before the Revolution, and is still used in Italy and Spain. In it the space between the boiling and freezing points is divided into 80°. The freezing point is marked 0, the boiling point 80°[‡].

De Lisle's thermometer is used in Russia. The space

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[*] This is the thermometer always used throughout this Work, unless when some other is particularly mentioned.

[†] Consequently the degrees of Fahrenheit are to those of Celsius, as $180 : 100 = 18 : 10 = 9 : 5$. That is, 9° of Fahrenheit are equal to 5° of Celsius. Therefore, to reduce the degrees of Celsius to those of Fahrenheit, we have $F = \frac{9\,C}{5} + 32$.

[‡] Consequently $180\,F = 80\,R$, or $18\,F = 8\,R$, or $9\,F = 4\,R$; therefore $F = \frac{9\,R}{4} + 32$.

between the boiling and freezing points is divided into 150°; but the graduation begins at the boiling point, and increases towards the freezing point. The boiling point is marked 0, the freezing point 150°*.

Does not measure the increase of heat.

9. In making experiments with the thermometer, we ought always to remember that, when graduated in the common way, it does not give us an exact measure of the increase of heat: For as the expansion of mercury for every degree of temperature increases with the temperature, it is obvious that, unless allowance be made for that increase, the degree indicated by the thermometer will not mark the number of degrees of heat added to or abstracted from a body, but another number, deviating more and more from the true one the higher the temperature indicated happens to be. Thus suppose the medium temperature between that of boiling and freezing water to be denoted by 122°; if we extend the scale upwards, the boiling water point will not be 212°, as it would be if the scale were equable, but 218°.4. On the other hand, if we fix the boiling and freezing points, as is commonly done, and mark them 212° and 32°, then the medium temperature between these two will not be 122°, but 118°.8.

Exceptions to expansion,

10. Having now considered the phenomena and laws of expansion as far as they are understood, it will be proper to state the exceptions to this general effect of heat, or the cases in which expansion is produced; not

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* Hence $180\ F = 150\ D$, or $6\ F = 5\ D$. To reduce the degrees of De Lisle's thermometer under the boiling point to those of Fahrenheit, we have $F = 212 - \frac{6\ D}{5}$; to reduce those above the boiling point, $F = 212 + \frac{6\ D}{5}$.

Of two kinds.

by an increase, but by a diminution of temperature. These exceptions may be divided into two classes. The first class comprehends certain liquid bodies which have a maximum of density corresponding with a certain temperature; and which, if they be heated above that temperature, or cooled down below it, undergo in both cases an expansion or increase of bulk. The second class comprehends certain liquids which suddenly become solid when cooled down to a certain temperature; and this solidification is accompanied by an increase of bulk.

1. Water at 42°.5 expands when cooled.

11. Water furnishes us with the most remarkable example of the first class of bodies. Its maximum of density corresponds with 42°.5 of Fahrenheit's thermometer, as has been lately ascertained by Mr Dalton *. If it be cooled down below 42°.5, it undergoes an expansion for every degree of temperature which it loses; and at 32° the expansion amounts, according to Mr Dalton, to $\frac{1}{160}$ of the whole expansion which water undergoes when heated from 42°.5 to 212° †. With this my experiments coincide very nearly; for by cooling 100000 parts in bulk of water from 42°.5 to 32°, I converted them to 100031 parts. We are indebted to the ingenuity of Mr Dalton for the discovery of a very unexpected fact, that the expansion of water is the same

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[*] *Manchester Memoirs*, v. 374. The fact, that water ceases to be condensed by cold was noticed long ago by Baumé; but Mr Deluc was the first philosopher who made precise and decisive experiments on the subject. His experiments were fully confirmed by those of Blagden and Gilpin. These philosophers fixed 40° as the maximum point of the density of water; and the fact is, that the difference in bulk between 41° and 44° is barely perceptible on the most delicate scale.

[†] Ibid.

for any number of degrees above or below the maximum of density. Thus if we heat water ten degrees above 42°.5, it occupies precisely the same bulk as it does when cooled down ten degrees below 42°.5. Therefore the density of water at 32° and at 53° is precisely the same. Mr Dalton succeeded in cooling water down to the temperature of 5° without freezing, or 37°.5 below the maximum point of density; and during the whole of that range, its bulk precisely corresponds with the bulk of water the same number of degrees above 42°.5. Thus the bulk of water at 5° is the same as the bulk of water at 80° [*]. The scale of expansion, therefore, which has been given for the expansion of water when heated, answers also for its expansion when cooled, provided the table begin at 42°.5, as is done in the table of the expansion of water which I have given above from my own experiments.

From this table it appears, that the expansion of water, the original bulk being 10000, may be expressed pretty nearly by the following numbers :

Temp.	Expan.
82°.5	6^2
102°.5	8^2
122°.5	10^2
142°.5	12^2
162°.5	14^2

The greatest deviation from these numbers is towards the beginning of the scale, when, owing to the smalness of the expansion, it is difficult to measure it with precision. It leads us to this remarkable conclusion, that the squares of the natural numbers beginning at 6 indi-

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[*] *Manchester Mem.* v. 375.

cate the increase of bulk which 10000 parts of water experience for every ten degrees they are heated above 82°.5, or cooled below 12°.5*. This rule will give the reader a more precise idea of the rate at which water expands, when heated or cooled, than a bare inspection of the table could do.

I tried a considerable number of liquids, to ascertain whether any of them, like water, have a temperature in which their density is a maximum, and which expand when cooled below that temperature. Sulphuric acid has no such point, neither have the oily bodies; but I thought I could perceive some solutions of salt in water beginning to expand before they became solid. But these solutions when cooled down sufficiently crystallize with such rapidity that it is extremely difficult to be certain of the fact, that they really do begin to expand before they crystallize.

2. Many liquids expand in crystallizing.

11. That class of bodies which undergo an expansion when they change from a liquid to a solid body by the diminution of temperature, is very numerous. Not only water when converted into ice undergoes such an expansion, but all bodies which by cooling assume the form of crystals.

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[*] Some later experiments made with more care give me the expansion of water somewhat greater than in the table; but the ratio is still the same. If we set off the numbers 6^2, 7^2, 8^2, 9^2, &c. denoting the expansions, upon a straight line, and draw from the points 6^2, 7^2, 8^2, 9^2, &c. perpendicular ordinates, the lengths of which are to each other as the number of degrees of temperature from 42°.5 indicated by the respective expansion; and if a curve be drawn through the extremities of these ordinates, it is obvious that this curve will be a common parabola, whose apex is at the temperature 42°.5, where the expansion is nothing, and extending on both sides the axis according as the degrees of temperature are positive or negative. This will be evident to every person by simply inspecting figure 10.

Expansion of ice.

The prodigious force with which water expands in the act of freezing has been long known to philosophers. Glass bottles filled with water are commonly broken in pieces when the water freezes. The Florentine academicians burst a brass globe whose cavity was an inch in diameter, by filling it with water and freezing it. The force necessary for this effect was calculated by Muschenbroeck at 27720 lbs. But the most complete set of experiments on the expansive force of freezing water are those made by Major Williams at Quebec, and published in the second volume of the Edinburgh Transactions. This expansion has been explained, by supposing it the consequence of a tendency which water, in consolidating, is observed to have to arrange its particles in one determinate manner, so as to form prismatic crystals, crossing each other at angles of 60° and 120°. The force with which they arrange themselves in this manner must be enormous, since it enables small quantities of water to overcome so great mechanical pressures. I tried various methods to ascertain the specific gravity of ice at 32°; the one which succeeded best was, to dilute spirits of wine with water till a mass of solid ice put into it remained in any part of the liquid without either sinking or rising. I found the specific gravity of such a liquid to be 0.92; which of course is the specific gravity of ice, supposing the specific gravity of water at 60° to be 1. This is an expansion much greater than water experiences even when heated to 212°. We see from this, that water, when converted into ice, no longer observes that equable expansion measured by Mr Dalton, but undergoes a very rapid and considerable augmentation of bulk.

The very same expansion is observed during the crystallization of most of the salts; all of them at least which shoot into prismatic forms. Hence the reason that the glass vessels in which such liquids are left usually break to pieces when the crystals are formed. A number of experiments on this subject have been published by Mr Vauquelin *.

This expansion of these bodies cannot be considered as an exception to the general fact, that bodies increase in bulk when heat is added to them; for the expansion is the consequence, not of the diminution of heat, but of the change in their state from liquids to solids, and the new arrangement of their particles which accompanies or constitutes that change.

Some bodies contract in freezing.

12. It must be observed, however, that all bodies do not expand when they become solid. There are a considerable number which diminish in bulk; and in these the rate of diminution in most cases is rather increased by solidification. When liquid bodies are converted into solids, they either form prismatic crystals, or they form a mass in which no regularity of arrangement can be perceived. In the first case, expansion accompanies solidification; in the second place, contraction accompanies it. Water and all the salts furnish instances of the first, and tallow and oils are examples of the second. In these last bodies the solidification does not take place instantaneously as in water and salts, but slowly and gradually; they first become viscid, and at last quite solid. Most of the oils, when they solidify, form very regular spheres. The same thing happens to honey

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* *Ann. de Chim.* xiv. 286.

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and to some of the metals, as mercury, which also contracts in the act of solidification.

From a considerable number of experiments which I made on this subject, I was disposed to draw this general conclusion, that all combustible liquids contract when they become solid, while all incombustible liquids expand : but there are several exceptions to this rule. Sulphuric acid, for instance, does not perceptibly expand when it congeals, nor does it in the least alter its appearance. Sulphuric acid, of the specific gravity 1.8, may be cooled down in thermometer tubes to —36° before it freezes ; and during the whole process it follows exactly the rate of expansion given in the table of expansions. At —36°, or about that temperature, it freezes; but its appearance is so little altered, that I could not satisfy myself whether or not the liquid was frozen till I broke the tube. It was perfectly solid, and displayed no appearance of crystallization. On the other hand, cast iron, and probably sulphur also, expands in the act of congealing.

SECOND EFFECT.

CHANGES IN THE STATE OF BODIES.

ALL substances in nature, as far as we are acquainted with them, occur in one or other of the three following states : namely, the state of solids, of liquids, or of elastic fluids or vapours. It has been ascertained, that in a vast number of cases, the same substance is capable of existing successively in each of these states. Thus sulphur is usually a solid body; but when heated to 212° it is converted into a liquid; and at a still higher temperature (about 570°), it assumes the form of an elastic vapour of a deep brown colour. Thus also water in our climate is usually a liquid; but when cooled down to 32 , it is converted into a solid body, and at 212° it assumes the form of an elastic fluid.

Bodies change their state by heat.

All solid bodies, a very small number excepted, may be converted into liquids by heating them sufficiently; and, on the other hand, every liquid, except spirit of wine, is convertible into a solid body by exposing it to a sufficient degree of cold. All liquid bodies may, by heating them, be converted into elastic fluids, and a great many solids are capable of undergoing the same change; and, lastly, the number of elastic fluids which by cold are condensible into liquids or solids is by no means inconsiderable. These facts have led philosophers to form this general conclusion, "that all bodies, if placed in a temperature sufficiently low, would assume a solid form; that all solids become liquids when sufficiently heated; and that all liquids, when exposed to a certain temperature, assume the form of elastic fluids." The state of bodies then depends upon the temperature in which they are placed; in the lowest temperatures they are all solid, in higher temperatures they are converted into liquids, and in the highest of all they become elastic fluids. The particular temperatures at which bodies undergo those changes, are exceedingly various, but they are always constant for the same bodies. Thus we see that heat produces changes on the state of bodies, converting them all, first into liquids, and then into elastic fluids.

Conversion of solids into liquids.

I. When solid bodies are converted by heat into liquids, the change in some cases takes place at once. There is no interval between solidity and liquidity; but in other cases a very gradual change may be perceived; the solid becomes first soft, and it passes slowly through all the degrees of softness, till at last it becomes perfectly fluid. The conversion of ice into water is an instance of the first change; for in that substance there is no intervening state between solidity and fluidity. The melting of glass, of wax, and of tallow, exhibits instances of the second kind of change; for these bodies pass through every possible degree of softness before they terminate in perfect fluidity. In general, those solid bodies which crystallize or assume regular prismatic figures, have no interval between solidity and fluidity; while those that do not usually assume such shapes, have the property of appearing successively in all the intermediate states.

Instantaneous or slow.

Takes place at a particular temperature.

1. Solid bodies never begin to assume a liquid form till they are heated to a certain temperature: this temperature is constant in all. In the first class of bodies it is very well defined; but in the second class, though it is equally constant, the exact temperature of fluidity cannot be pointed out with such precision, on account of the infinite number of shades of softness through which the bodies pass before they acquire their greatest possible fluidity. But even in these bodies we can easily ascertain, that the same temperature always produces the same degree of fluidity. The temperatures at which this change from solidity to liquidity takes place, receive different names according to the usual state of the body thus changed. When the body is usually observed in a liquid state, we call the temperature at which

it assumes the form of a solid, its *freezing point*, or *congealing point*. Thus the temperature in which water becomes ice, is called the *freezing point* of water; on the other hand, when the body is usually in the state of a solid, we call the temperature at which it liquifies its *melting point*: thus 212° is the melting point of sulphur; 442° the melting point of tin.

Table of melting points.

2. The following Table contains a list of the melting point of a considerable number of solid bodies:

Substance.	Melting Point.
Lead	594°
Bismuth	576
Tin	442
Sulphur	212
Wax	142*
Spermaceti	133
Phosphorus	100
Tallow	92
Oil of anise	50
Olive oil	36
Ice	32
Milk	30°
Vinegar	28
Blood	25
Oil of Bergamot	23
Wines	20
Oil of turpentine	14
Sulphuric acid	—36
Mercury	—39
Liquid ammonia	—46
Ether	—46
Nitric acid	—66

Dr Black's opinion,

3. Before Dr Black began to deliver his chemical lectures in Glasgow in 1757, it was universally supposed that solids were converted into liquids by a small addition of heat, after they have been once raised to the melting point, and that they returned again to the solid state on a very small diminution of the quantity of heat necessary to keep them at that temperature. An attentive view of the phenomena of liquefaction and solidification gradually led this sagacious philosopher

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* Bleached Wax, 155°; *Nicholson*.

to observe their inconsistence with the then received opinions, and to form another, which he verified by direct experiments ; and drew up an account of his theory, and the proofs of it, which was read to a literary society in Glasgow on April 23d. 1762 * ; and every year after he gave a detailed account of the whole doctrine in his lectures.

That fluidity is occasioned by latent heat,

The opinion which he formed was, that when a solid body is converted into a liquid, a much greater quantity of heat enters into it than is perceptible immediately after by the thermometer. This great quantity of heat does not make the body apparently warmer, but it must be thrown into it in order to convert it into a liquid ; and this great addition of heat is the principal and most immediate cause of the fluidity induced. On the other hand, when a liquid body assumes the form of a solid, a very great quantity of heat leaves it without sensibly diminishing its temperature ; and the state of solidity cannot be induced without the abstraction of this great quantity of heat. Or, in other words, whenever a solid is converted into a fluid, it combines with a certain dose of caloric, without any augmentation of its temperature ; and it is this dose of caloric which occasions the change of the solid into a fluid. When the fluid is converted again into a solid, the dose of caloric leaves it, without any diminution of its temperature ; and it is this abstraction which occasions the change. Thus the combination of a certain dose of caloric with ice causes it to become water, and the abstraction of a certain dose of caloric from water causes it to become

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* Blacks *Lectures*, Preface, p. 38.

ice. Water, then, is a compound of ice and caloric; and in general all fluids are combinations of the solid, to which they may be converted by cold, and a certain dose of caloric.

Such is the opinion concerning the cause of fluidity taught by Dr Black as early as 1762. Its truth was established by the following experiments:

Proved by experiments.

First. If a lump of ice, at the temperature of 22°, be brought into a warm room, in a very short time it is heated to 32°, the freezing point. It then begins to melt; but the process goes on very slowly, and several hours elapse before the whole ice is melted. During the whole of that time its temperature continues at 32°; yet as it is constantly surrounded by warm air, we have reason to believe that caloric is constantly entering into it. Now as none of this caloric is indicated by the thermometer, what becomes of it, unless it has combined with that portion of the ice which is converted into water, and unless it is the cause of the melting of the ice?

Dr Black took two thin globular glasses, four inches in diameter, and very nearly of the same weight. Both were filled with water; the contents of the one were frozen into a solid mass of ice, the contents of the other were cooled down to 33°; the two glasses were then suspended in a large room at a distance from all other bodies, the temperature of the air being 47°. In half an hour the thermometer placed in the water glass rose from 33° to 40°, or 7 degrees; the ice was at first 4 or 5 degrees colder than melting snow; but in a few minutes the thermometer applied to it stood at 32°. The instant of time when it reached that temperature was noted, and the whole left undisturbed for ten hours and a half. At the end of that time the whole ice was melted, except a very small spongy mass, which floated at the top and disappeared in a few minutes. The temperature of the ice water was 40°.

Thus 10½ hours were necessary to melt the ice and raise the product to the temperature of 40°. During all this time it must have been receiving heat with the same celerity as the water glass received it during the first half hour. The whole quantity received then was 21 times 7, or 147°; but its temperature was only 40°: therefore 139 or 140 degrees had been absorbed by the melting ice, and remained concealed in the water into which it had been converted, its presence not being indicated by the thermometer *.

That heat is actually entering into the ice is easily ascertained by placing the hand on a thermometer under the vessel containing it. A current of cold air may be perceived descending from it during the whole time of the process.

But it will be said, perhaps, that the heat which enters into the ice does not remain there, but is altogether destroyed. This opinion is refuted by the following experiment.

Second. If, when the thermometer is at 22°, we expose a vessel full of water at 52° to the open air, and beside it another vessel full of brine at the same temperature, with thermometers in each; we shall find that both of them gradually lose caloric, and are cooled down to 32°. After this the brine (which does not freeze till cooled down to 0°) continues to cool without interruption,

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* Black's *Lectures*, i. 120.

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and gradually reaches 22°, the temperature of the air; but the pure water remains stationary at 32°. It freezes indeed, but very slowly; and during the whole process its temperature is 32°. Now, why should the one liquid refuse all of a sudden to give out caloric and not the other? Is it not much more probable that the water, as it freezes, gradually gives out the heat which it had absorbed during its liquefaction; and that this evolution maintains the temperature of the water at 32°, notwithstanding what it parts with to the air during the whole process? We may easily satisfy ourselves that the water while congealing is constantly imparting heat to the surrounding air; for a delicate thermometer suspended above it is constantly affected by an ascending stream of air less cold than the air around*. The following experiment, first made by Fahrenheit, and afterwards often repeated by Dr Black and others, affords a palpable evidence, that such an evolution of caloric actually takes place during congelation.

Third. If when the air is at 22°, we expose to it a quantity of water in a tall beer glass, with a thermometer in it and covered, the water gradually cools down to 22° without freezing. It is therefore 10° below the freezing point. Things being in this situation, if the water be shaken, part of it instantly freezes into a spongy mass, and the temperature of the whole instantly rises to the freezing point; so that the water has acquired ten degrees of caloric in an instant. Now whence came these ten degrees? Is it not evident that it must have

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* Black's *Lectures*, i. 127.

come from that part of the water which was frozen, and consequently that water in the act of freezing gives out caloric?

From a good many experiments which I have made on water in these circumstances, I have found reason to conclude, that the quantity of ice which forms suddenly on the agitation of water, cooled down below the freezing point, bears always a constant ratio to the coldness of the liquid before agitation. Thus I find, that when water is cooled down to 22°, very nearly $\frac{1}{14}$ of the whole freezes[†]; when the previous temperature is 27°, about $\frac{1}{28}$ of the whole freezes. I have not been able to make satisfactory experiments in temperatures lower than 22°; but from analogy I conclude, that for every 5 degrees of diminution of temperature below the freezing point, without congelation, $\frac{1}{28}$ of the liquid freezes suddenly on agitation. Therefore, if water could be cooled down 28 times 5 degrees below 32° without congelation, the whole would congeal instantaneously on agitation, and the temperature of the ice would be 32°. Now it deserves attention, that $5 \times 28 = 140$ gives us precisely the quantity of heat which, according to Dr Black's experiments, enters into ice in order to convert it into water. Hence it follows, that in all cases when water is cooled down below 32°, it loses a portion of the caloric which is necessary to constitute its liquidity. The instant that such water is agitated, one portion of the liquid seizes upon the quantity of caloric in which it is deficient at the expence of another portion, which of course becomes ice. Thus when water is cooled down

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[*] A medium of several experiments.

to 22°, every particle of it wants 10° of the caloric necessary to keep it in a state of liquidity. Thirteen parts of it seize ten degrees each from the fourteenth part. These thirteen of course acquire the temperature of 32°; and the other part, being deprived of $10 \times 13 = 130$, which with the ten degrees that it had lost before constitute 140°, or the whole of the caloric necessary to keep it fluid, assumes of consequence the form of ice.

Fourth. If these experiments should not be considered as sufficient to warrant Dr Black's conclusion, the following, for which we are indebted to the same philosopher, puts the truth of his opinion beyond the reach of dispute. He mixed together given weights of ice at 32° and water at 190° of temperature. The ice was melted in a few seconds, and the temperature produced was 53°. The weight of the ice was 119 half-drachms;

That of the hot water, . . . 135
of the mixture, ... 254
of the glass vessel, . . 16

Sixteen parts of glass have the same effect in heating cold bodies as eight parts of equally hot water. Therefore, instead of the 16 half-drachms of glass, 8 of water may be substituted, which makes the hot water amount to 143 half-drachms.

In this experiment there were 158 degrees of heat contained in the hot water to be divided between the ice and the water. Had they been divided equally, and had the whole been afterwards sensible to the thermometer, the water would have retained $\frac{143}{262}$ parts of this heat, and the ice would have received $\frac{119}{262}$ parts. That is to say, the water would have retained 86°, and the ice would have received 72°; and the temperature after mixture would have been 104°. But the temperature by experiment is found to be only 53°; the hot water lost 137°, and the ice only received an addition of temperature equal to 21°. But the loss of 18° of temperature in the water is equivalent to the gain of 21° in the ice. Therefore 158° — 18° = 140° of heat have disappeared altogether from the hot water. These 140° must have entered into the ice, and converted it into water without raising its temperature *.

In the same manner, if we take any quantity of ice, or (which is the same thing) snow at 32°, and mix it with an equal weight of water at 172°, the snow instantly melts, and the temperature of the mixture is only 32°. Here the water is cooled 140°, while the temperature of the snow is not increased at all; so that 140° of caloric have disappeared. They must have combined with the snow; but they have only melted it without increasing its temperature. Hence it follows irresistibly, that ice, when it is converted into water, absorbs and combines with 140° of caloric.

Latent heat of water,

Water, then, after being cooled down to 32°, cannot freeze till it has parted with 140° of caloric; and ice, after being heated to 32°, cannot melt till it has absorbed 140° of caloric. This is the cause of the extreme slowness of these operations. With regard to water, then, there can be no doubt that it owes its fluidity to the caloric which it contains, and that the caloric necessary to give fluidity to ice is equal to 140°.

To the quantity of caloric which thus occasions the fluidity of solid bodies by combining with them, Dr Black gave the name of *latent heat*, because its presence

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* Black's *Lectures*, i. 123.

is not indicated by the thermometer; a term sufficiently expressive, but other philosophers have rather chosen to call it *caloric of fluidity*.

Dr Black and his friends ascertained also, by experiment, that the fluidity of melted wax, tallow, spermaceti, metals, is owing to the same cause. Landriani proved, that this is the case with sulphur, alum, nitre, and several of the metals *; and it has been found to be the case with every substance hitherto examined. We may consider it therefore as a general law, that whenever a solid is converted into a fluid, it combines with caloric, and that this is the cause of its fluidity.

Of other bodies.

4. From the experiments of Dr Irvine †, it appears that the caloric of fluidity of spermaceti is 145°

Bees Wax	175
Tin . . .	500

These are the only substances in which the quantity of caloric, absorbed during fusion, has been ascertained. In all of them we see this rule to hold, that the caloric of fluidity increases with the temperature at which liquidity takes place.

Softness and ductility owing to the same cause.

5. Dr Black has rendered it exceedingly probable also, or rather he has proved by his experiments and observations, that the softness of such bodies as are rendered plastic by heat, depends upon a quantity of latent heat which combines with them. Metals also owe their malleability and ductility to the same cause. Hence the reason that they become hot and brittle when hammered.

II. Thus it appears, that the conversion of solids in-

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* *Jour. de Phys.* xxv.

† Black's *Lectures*, v. i. p. 187.

to liquids, is occasioned by the combination of a dose of caloric with the solid. But there is another change of state still more remarkable, to which bodies are liable when exposed to the action of heat. Almost all liquids, when raised to a certain temperature, gradually assume the form of an elastic fluid, invisible like air, and possessed of the same mechanical properties. Thus water, by boiling, is converted into steam, an invisible fluid, 1800 times more bulky than water, and as elastic as air. These fluids retain their elastic form as long as their temperature remains sufficiently high; but when cooled down again, they lose that form, and are converted into liquids. All liquids, and even a considerable number of solids, are capable of undergoing this change when sufficiently heated.

Some bodies become vapour at all temperatures, others not.

2. With respect to the temperatures at which liquids undergo this change, they may be all arranged under two divisions. There are some liquids which are gradually converted into elastic fluids at every temperature; while others again never begin to assume that change till their temperature reaches a certain point. Water is a well known example of the first class of bodies. If an open vessel, filled with water, be carefully examined, we find that the water diminishes in bulk day after day, and at last disappears altogether. If the experiment be made in a vessel sufficiently large, and previously exhausted of air, we shall find, that the water will fill the vessel in the state of invisible vapour, in whatever temperature it be placed: alcohol likewise, and ether, and volatile oils, gradually assume the form of an elastic fluid in all temperatures. But sulphuric acid and the fixed oils never begin to assume the form of vapour till they are raised to a certain temperature. Though

left in open vessels they lose no perceptible weight; neither does sulphuric acid lose any weight though kept ever so long in the temperature of boiling water. When liquids gradually assume the form of elastic fluids in all temperatures, they are said to *evaporate* spontaneously. The second class of liquids want that property altogether.

Boiling explained.

3. When all other circumstances are the same, the evaporation of liquids increases with their temperature; and after they are heated to a certain temperature, they assume the form of elastic fluids with great rapidity. If the heat be applied to the bottom of the vessel containing the liquids, as is usually the case, after the whole liquid has acquired this temperature, those particles of it which are next the bottom become an elastic fluid first: they rise up, as they are formed, through the liquid, like air-bubbles, and throw the whole into violent agitation. The liquid is then said to *boil*. Every particular liquid has a fixed point at which this boiling commences (other things being the same); and this is called the boiling point of the liquid. Thus water begins to boil when heated to 212°. It is remarkable, that after a liquid has begun to boil, it never becomes any hotter, however strong the fire be to which it is exposed. A strong heat indeed makes it boil more rapidly, but does not increase its temperature. This was first observed by Dr Hooke.

Boiling points

4. The following Table contains the boiling point of a number of liquids.

Bodies.	Boiling Point.	Bodies.	Boiling Point.
Ether	98°	Sulphuric acid	590 †
Ammonia	140 †	Phosphorus	554
Alcohol	176	Oil of turpentine	560
Water	212	Sulphur	570
Muriat of lime	230 †	Linseed oil	600
Nitric acid	248	Mercury	660 †

Vary with the pressure.

5. It was observed, when treating of the melting point of solids, that it is capable of being varied considerably by altering the situation of the body. Thus water may be cooled down considerably lower than 32° without freezing. The boiling point is still less fixed, depending entirely on the degree of pressure to which the liquid to be boiled is exposed. If we diminish the pressure, the liquid boils at a lower temperature; if we increase it, a higher temperature is necessary to produce ebulition. From the experiments of Professor Robison, it appears that, in a vacuum, all liquids boil about 145° lower than in the open air, under a pressure of 30 inches of mercury; therefore water would boil in vacuo at 67°, and alcohol at 34°. In a Papin's digester, the temperature of water may be raised to 300°, or even 400°, without ebulition: But the instant that this great pressure is removed, the boiling commences with prodigious violence.

Elasticity of vapours increases with the temperatures.

6. The elasticity of all the elastic fluids into which liquids are converted by heat, increases with the temperature; and the vapour formed, when the liquid boils in the open air, possesses an elasticity just equal to that of air, or capable at a medium of balancing a column of mercury 30 inches high. The following

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† Dalton.

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very important TABLE, drawn up by Mr Dalton * from his own experiments, exhibits the elasticity of steam, or the vapour of water of every temperature, from —40° to 325°. The elasticities of all the temperatures from 32° to 212° were ascertained by experiment; the rest were calculated by observing the rate at which the elasticity increased or diminished according to the temperature.

Table of the elasticity of steam.

Temperature	Force of Vap. in inches of Mercury.	Temperature.	Force of Vap. in inches of Mercury.	Temperature.	Force of Vap. in inches of Mercury.	Temperature.	Force of Vap. in inches of Mercury.
−40°	.013	15°	.108	34°	.214	54°	.429
−30	.020	16	.112	35	.221	55	.443
−20	.030	17	.116	36	.229	56	.458
−10	.043	18	.120	37	.237	57	.474
		19	.124	38	.245	58	.490
0	.064	20	.129	39	.254	59	.507
1	.066	21	.134	40	.263	60	.524
2	.068	22	.139	41	.273	61	.542
3	.071	23	.144	42	.283	62	.560
4	.074	24	.150	43	.294	63	.578
5	.076	25	.156	44	.305	64	.597
6	.079	26	.162	45	.316	65	.616
7	.082	27	.168	46	.328	66	.635
8	.085	28	.174	47	.339	67	.655
9	.087	29	.180	48	.351	68	.676
10	.090	30	.186	49	.363	69	.698
11	.093	31	.193	50	.375	70	.721
12	.096			51	.388	71	.745
13	.100	32	.200	52	.401	72	.770
14	.104	33	.207	53	.415	73	.796

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* *Manchester Mem.* v. 559.

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TABLE *continued.*

Temperature.	Force of Vap. in inches of Mercury.	Temperature.	Force of Vap. in inches of Mercury.	Temperature.	Force of Vap. in inches of Mercury.	Temperature.	Force of Vap. in inches of Mercury.
74°	.823	106°	2.25	138°	5.44	170°	12.13
75	.851	107	2.32	139	5.59	171	12.43
76	.880	108	2.39	140	5.74	172	12.73
77	.910	109	2.46	141	5.90	173	13.02
78	.940	110	2.53	142	6.05	174	13.32
79	.971	111	2.60	143	6.21	175	13.62
80	1.00	112	2.68	144	6.37	176	13.92
81	1.04	113	2.76	145	6.53	177	14.22
82	1.07	114	2.84	146	6.70	178	14.52
83	1.10	115	2.92	147	6.87	179	14.83
84	1.14	116	3.00	148	7.05	180	15.15
85	1.17	117	3.08	149	7.23	181	15.50
86	1.21	118	3.16	150	7.42	182	15.86
87	1.24	119	3.25	151	7.61	183	16.23
88	1.28	120	3.33	152	7.81	184	16.61
89	1.32	121	3.42	153	8.01	185	17.00
90	1.36	122	3.50	154	8.20	186	17.40
91	1.40	123	3.59	155	8.40	187	17.80
92	1.44	124	3.69	156	8.60	188	18.20
93	1.48	125	3.79	157	8.81	189	18.60
94	1.53	126	3.89	158	9.02	190	19.00
95	1.58	127	4.00	159	9.24	191	19.42
96	1.63	128	4.11	160	9.46	192	19.86
97	1.68	129	4.22	161	9.68	193	20.32
98	1.74	130	4.34	162	9.91	194	20.77
99	1.80	131	4.47	163	10.15	195	21.22
100	1.86	132	4.60	164	10.41	196	21.68
101	1.92	133	4.73	165	10.68	197	22.13
102	1.98	134	4.86	166	10.96	198	22.69
103	2.04	135	5.00	167	11.25	199	23.16
104	2.11	136	5.14	168	11.54	200	23.64
105	2.18	137	5.29	169	11.83	201	24.12

TABLE *continued.*

Temperature.	Force of Vap. in inches of Mercury.	Temperature.	Force of Vap. in inches of Mercury.	Temperature.	Force of Vap. in inches of Mercury.	Temperature.	Force of Vap. in inches of Mercury.
202°	24.61	233°	44.00	265°	72.76	297°	108.31
203	25.10	234	44.78	266	73.77	298	109.48
204	25.61	235	45.58	267	74.79	299	110.64
205	26.13	236	46.39	268	75.80	300	111.81
206	26.66	237	47.20	269	76.82	301	112.98
207	27.20	238	48.02	270	77.85	302	114.15
208	27.74	239	48.84	271	78.89	303	115.32
209	28.29	240	49.67	272	79.94	304	116.50
210	28.84	241	50.50	273	80.98	305	117.68
211	29.41	242	51.34	274	82.01	306	118.86
212	30.00	243	52.18	275	83.13	307	120.03
		244	53.03	276	84.35	308	121.20
213	30.60	245	53.88	277	85.47	309	122.37
214	31.21	246	54.68	278	86.50	310	123.53
215	31.83	247	55.54	279	87.63	311	124.69
216	32.46	248	56.42	280	88.75	312	125.85
217	33.09	249	57.31	281	89.87	313	127.00
218	33.72	250	58.21	282	90.99	314	128.15
219	34.35	251	59.12	283	92.11	315	129.29
220	34.99	252	60.05	284	93.23	316	130.43
221	35.63	253	61.00	285	94.35	317	131.57
222	36.25	254	61.92	286	95.48	318	132.72
223	36.88	255	62.85	287	96.64	319	133.86
224	37.53	256	63.76	288	97.80	320	135.00
225	38.20	257	64.82	289	98.96	321	136.14
226	38.89	258	65.78	290	100.12	322	137.28
227	39.59	259	66.75	291	101.28	323	138.42
228	40.30	260	67.73	192	102.45	324	139.56
229	41.02	261	68.72	293	103.63	325	140.70
230	41.75	262	69.72	294	104.80		
231	42.49	263	70.73	295	105.97		
232	43.24	264	71.74	296	107.14		

Elasticity of all vapours equal at equal distances from the boiling point.

Mr Dalton has discovered, that the elasticity of every other *vapour* or *steam* is precisely the same with that of the steam of water at the same distance from its boiling point. Thus water boils at 212°; its elasticity at the temperature of 182°, or 30° under its boiling point, we see from the table is 15.86. Alcohol boils at 176°; the elasticity of the steam of alcohol at 146°, or 30° under its boiling point, is likewise 15.86. This very important discovery enables us to ascertain the elasticity of the vapours of all liquids whatever at any temperature, provided their boiling points be known. We have only to find how many degrees the temperature at which the elasticity required is distant from the boiling point of this liquid. The same number of degrees, added or substracted from 212°, gives us a temperature, opposite to which in the above table we shall find the elasticity required.

Vapours are liquids combined with caloric.

7. Such are the phenomena of the conversion of liquid into elastic fluids. Dr Black applied his theory of latent heat to this conversion with great sagacity; and demonstrated, that it is owing to the very same cause as the conversion of solids into liquids; namely, to the combination of a certain dose of caloric with the liquid without any increase of temperature. The truth of this very important point was established by the following experiments.

First. When a vessel of water is put upon the fire, the water gradually becomes hotter till it reaches 212°; but afterwards its temperature is not increased. Now caloric must be constantly entering from the fire and combining with the water. But as the water does not become hotter, the caloric must combine with that part of it which flies off in the form of steam: but the temperature of the steam is only 212°; therefore the caloric combined with it does not increase its temperature. We must conclude, then, that the change of water to steam is owing to the combination of this caloric; for it produces no other change.

Dr Black put some water in a tin-plate vessel upon a red hot iron. The water was of the temperature 50°: in 4 minutes it began to boil, and in 20 minutes it was all boiled off. During the first 4 minutes it had received 162°, or $40\frac{1}{2}$ per minute. If we suppose that it received as much per minute during the whole process of boiling, the caloric which entered into the water and converted it into steam would amount to $40\frac{1}{2} \times 20 = 810°$[*]. This caloric is not indicated by the thermometer, for the temperature of steam is only 212°; therefore Dr Black called it *latent heat*.

Second. Water may be heated in a Papin's digester to 400° without boiling; because the steam is forcibly compressed, and prevented from making its escape. If the mouth of the vessel be suddenly opened while things are in this state, part of the water rushes out in the form of steam, but the greater part still remains in the form of water, and its temperature instantly sinks to 212 ; consequently 188° of caloric have suddenly disappeared. This caloric must have been carried off by the steam. Now as only about $\frac{1}{5}$ of the water is converted into steam, that steam must contain not only its own 188°, but also the 188° lost by each of the other four parts; that is to say, it must contain 188° × 5, or about 940°. Steam, therefore, is water combined with

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[*] Black's *Lectures*, i. 157.

at least 940° of caloric, the presence of which is not indicated by the thermometer. This experiment was first made by Dr Black, and afterwards with more precision by Mr Watt.

Third. When hot liquids are put under the receiver of an air pump, and the air is suddenly drawn off, the liquids boil, and their temperature sinks with great rapidity a considerable number of degrees. Thus water, however hot at first, is very soon reduced to the temperature of 70°; and ether becomes suddenly so cold that it freezes water placed round the vessel which contains it. In these cases the vapour undoubtedly carries off the heat of the liquid; but the temperature of the vapour is never greater than that of the liquid itself: the heat therefore must combine with the vapour, and become latent.

Fourth. If one part of steam at 212 be mixed with nine parts by weight of water at 62°, the steam instantly assumes the form of water, and the temperature after mixture is 178.6°; consequently each of the nine parts of water has received 116.6° of caloric; consequently the steam has lost 9 × 116.6° = 1049.4° of caloric. But as the temperature of the steam is diminished by 33.3°, we must subtract this sum. There will remain rather more than 1000°, which is the quantity of caloric which existed in the steam without increasing its temperature. This experiment cannot be made directly; but it may be made by passing a given weight of steam through a metallic worm, surrounded by a given weight of water. The heat acquired by the water indicates the caloric which the steam gives out during its condensation. From the experiments of Mr Watt made in this manner, it appears that the latent heat of steam amounts to 940°. The experiments of Mr Lavoisier make it rather more than 1000°.

By the experiments of Dr Black and his friends, it was ascertained, that not only water, but all other liquids during their conversion into vapour, combine with a dose of caloric, without any change of temperature; and that every kind of elastic fluid, during its conversion into a liquid, gives out a portion of caloric without any change of temperature. Dr Black's law, then, is very general, and comprehends every change in the state of a body. The cause of the conversion of a solid into a liquid is the combination of the solid with caloric; that of the conversion of a liquid into an elastic fluid is the combination of the liquid with caloric. Liquids are solids combined with caloric; elastic fluids are liquids combined with caloric. This law, in its most general form, may be stated as follows: *Whenever a body changes its state, it either combines with caloric or separates from caloric.*

General law discovered by Dr Black.

No person will dispute that this is one of the most important discoveries hitherto made in chemistry. Science is indebted for it entirely to the sagacity of Dr Black. Other philosophers indeed have laid claim to it; but these claims are either without any foundation, or their notions may be traced to Dr Black's lectures, as their opinions originated many years posterior to the public explanation of Dr Black's theory in the chemical chairs of Glasgow and Edinburgh.

Gases

III. A very considerable number of bodies, both solids and liquids, may be converted into elastic fluids by heat; and as long as the temperature continues sufficiently high, they retain all the mechanical properties of gaseous bodies. It is exceedingly probable, that if we could command a heat sufficiently intense, the same change might be produced on all bodies in nature. This accordingly is the opinion at present admitted by philosophers. But if all bodies are convertible into elastic fluids by heat, it is exceedingly probable, that all elastic fluids in their turn might be converted into solids or liquids, if we could expose them to a low enough temperature. In that case, all the gases must be supposed to owe their elasticity to a certain dose of caloric: they must be considered as compounds of caloric with a solid or liquid body. This opinion was first stated by Amontons; and it was supported, with much ingenuity, both by Dr Black and by Lavoisier and his associates. It is at present the prevailing opinion; and it is certainly supported not only by analogy, but by several very striking facts.

Supposed to be liquids combined with caloric.

1. If its truth be admitted, we must consider all the gases as capable of losing their elasticity by depriving them of their heat: they differ merely from the vapours in the great cold which is necessary to produce this change. Now the fact is, that several of the gases may be condensed into liquids by lowering their temperatures. Oxy-muriatic acid gas becomes liquid at a temperature not much under 40°; and at 32° it even forms solid crystals. Ammoniacal gas condenses into a liquid at —45°. None of the other gases have been hitherto condensed.

Condensed by cold

2. It is well known, that the condensation of vapours is greatly assisted by pressure; but the effect of pressure diminishes as the temperature of vapours increases. It is very likely that pressure would also contribute to assist the condensation of gases. It has been tried without effect indeed in several of them.

And pressure.

Thus air has been condensed till it was heavier than water; yet it showed no disposition to lose its elasticity. But this may be ascribed to the high temperature at which the experiment was made relative to the point at which air would lose its elasticity.

Objections to the opinion.

3. At the same time it cannot be denied, that there are several phenomena scarcely reconcilable to this constitution of the gases, ingenious and plausible as it is. One of the most striking is the sudden solidification which ensues when certain gases are mixed together. Thus when ammoniacal gas and muriatic acid gas are mixed, the product is a solid salt: yet the heat evolved is very inconsiderable, if we compare it with the difficulty of condensing these gases separately, and the great cold which they endure before losing their elasticity. In other cases, too, gaseous bodies unite, and form a new gas, which retains its elasticity as powerfully as ever. Thus oxygen gas and nitrous gas combined form a new gas, namely, nitric acid, which is permanent till it comes into contact with some body on which it can act.

THIRD EFFECT.

CHANGES IN COMPOSITION.

Caloric decomposes bodies.

CALORIC not only increases the bulk of bodies, and changes their state from solids to liquids and from liquids to elastic fluids; but its action decomposes a great number of bodies altogether, either into their elements, or it causes these elements to combine in a different manner. Thus when ammonia is heated to redness, it is resolved into azotic and hydrogen gases. Alcohol, by the same heat, is converted into carbureted hydrogen and water.

1. This decomposition is in many cases owing to the difference between the volatility of the ingredients of a compound. Thus when weak spirits, or a combination of alcohol and water, are heated, the alcohol separates, because it is more volatile than the water.

2. In general, the compounds which are but little or not at all affected by heat, are those bodies which have been formed by combustion. Thus water is not decomposed by any heat which can be applied to it; neither are sulphuric, phosphoric, or carbonic acids.

3. Almost all the combinations into which oxygen enters without having occasioned combustion, are decomposable by heat. This is the case with nitric acid, hyperoxymuriatic acid, and many of the metallic oxides.

4. All bodies that contain combustibles as component parts are decomposed by heat. Perhaps the metallic alloys are exceptions to this rule; at least it is not in our power to apply a temperature high enough to produce their decomposition, except in a few cases.

5. When two combustible ingredients and likewise oxygen occur together in bodies, they are always very easily decomposed by heat. This is the case with the greater number of animal and vegetable substances.

But it is unnecessary to enlarge any farther on this subject, as no satisfactory theory can be given. The decompositions will all be noticed in describing the different compounds which are to occupy our attention in the subsequent part of this Work.

SECT. V.

OF THE QUANTITY OF CALORIC IN BODIES.

HAVING, in the second Section of this Chapter, shewn that caloric is capable of moving through all bodies; and in the third, that it gradually diffuses itself through all contiguous bodies in such a manner that they assume the same temperature—the next point of discussion which presented itself was the quantity of caloric in bodies. When different bodies have the same temperature, do they contain the same quantity of caloric? Is the same quantity necessary to produce the same change of temperature in all bodies? What is the point at which a thermometer would stand if it were plunged into a body deprived of heat altogether? or what is the commencement of the scale of temperature? But these questions could not be examined with any chance of success while we were ignorant of the effects which caloric produces on bodies; because it is by these effects alone that the quantity of caloric in bodies is measured. This rendered it necessary for us to employ the fourth Section in the examination of these effects. Let us now apply the knowledge which we have acquired to the investigation of the quantity of caloric in bodies. This investigation naturally divides itself into three parts: 1. The relative quantities of caloric in bodies, or the quantities in each necessary to produce a given change of temperature. This is usually termed *specific caloric*. 2. The absolute quantity of caloric which exists in bodies. 3. The phenomena of *cold*, or the absence of caloric. These three topics shall be examined in order.

I. OF THE SPECIFIC CALORIC OF BODIES.

Specific caloric explained.

If equal weights of water and mercury, at different temperatures, be mixed together and agitated, it is natural to expect that the mixture would acquire the mean temperature. Suppose, for instance, that the temperature of the water were 100°, and that of the mercury 50°, it is reasonable to suppose that the water would be cooled 25°, and the mercury heated 25°, and that the temperature after mixture would be 75°. But when the experiment is tried the result is very far from answering this apparently reasonable expectation: for the temperature after mixture is 88°; consequently the water has only lost 12°, while the mercury has gained 38°. On the other hand, if we mix together equal weights of water at 50°, and mercury at 100°, the temperature, after agitation, will be only 62°; so that the mercury has given out 38°, and the water has received only 12°. This experiment demonstrates, that the same quantity of caloric is not required to raise mercury a given number of degrees which is necessary to raise water the same number. The quantity of caloric which raises mercury 38°, raises water only 12°; consequently the caloric which raises the temperature of water 1° will raise that of the same weight of mercury 3.16°.

If other substances be tried in the same manner, it will be found that they all differ from each other in the quantity of caloric which is necessary to heat each of them to a given temperature; some requiring more than the same weight of water would do, others less;

but every one requires a quantity peculiar to itself. Now the quantity of caloric which a body requires, in order to be heated to a certain temperature (one degree for instance), is called the *specific caloric* of that body. We do not indeed know the absolute quantity of caloric which is required to produce a certain degree of heat in any body; but if the unknown quantity necessary to heat water (1° for instance) be made = 1, we can determine, by experiment, how much more, or how much less caloric other bodies require to be heated the same number of degrees. Thus if we find by trial that the quantity of caloric which heats water 1°, heats the same weight of mercury 3.16°, it follows, that the specific caloric of water is 3.16 times greater than that of mercury; therefore if the specific caloric of water = 1, that of mercury must be = 0.31. In this manner may the specific caloric of all bodies be found.

History.

That the specific caloric of bodies is different, was first pointed out by Dr Black in his lectures at Glasgow between 1760 and 1765 *. Dr Irvine afterwards investigated the subject between 1765 and 1770 †; and Dr Crawford published a great number of experiments on it in his *Treatise on Heat*. These three philosophers denoted this property by the phrase *capacity of bodies for heat*. But Professor Wilcke of Stockholm, who published the first set of experiments on the subject, introduced the term *specific caloric;* which has been generally adopted, because the phrase *capacity for caloric* is liable to a great deal of ambiguity, and has introduced confusion into this subject ‡.

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* Black's *Lectures* i. 504. † Ibid.

‡ The term *specific caloric* has been employed in a different sense by Seguin. He used it for the *whole caloric* which a body contains.

The experiments of Mr Wilcke were first published in the Stockholm Transactions for 1772, but had been read to the Swedish Academy as early as 1771. The manner in which they were conducted is exceedingly ingenious, and they furnish us with the specific caloric of many of the metals. The metal on which the experiment was to be made was first weighed accurately (generally one pound was taken), and then being suspended by a thread, was plunged into a large vessel of tinplate, filled with boiling water, and kept there till it acquired a certain temperature, which was ascertained by a thermometer. Into another small box of tinplate exactly as much water at 32° was put as equalled the weight of the metal. Into this vessel the metal was plunged, and suspended in it so as not to touch its sides or bottom; and the degree of heat, the moment the metal and water were reduced to the same temperature, was marked by a very accurate thermometer. From the change of temperature, he deduced, by a very ingenious calculation, the specific caloric of the metal, that of water being considered as unity *.

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* The following is the process of reasoning by which he was lead to his conclusions. He first calculated what the temperature would have been if a quantity of water, equal in *weight* to the metal, and of the same temperature with it, had been added to the ice-cold water instead of the metal.

Let M be a quantity of water at the temperature C, m another quantity at the temperature c, and let their common temperature after mixture be x; according to a rule demonstrated long ago by Richman, $x = \frac{MC + mc}{M + m}$. In the present case the quantities of water are equal, therefore M and m are each $= 1$; C, the temperature of the ice-cold water, $= 32$: therefore $\frac{MC + mc}{M + m} = \frac{32 + c}{2}$. Now c is the temperature of the metal. Therefore if 32 be added to the temperature of the metal, and

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Next, in point of time, and not inferior in ingenious contrivances to ensure accuracy, were the experiments of Dr Crawford, made by mixing together bodies of

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the whole be divided by 2, the quotient will express the temperature of the mixture, if an equal weight of water with the metal, and of the same temperature with it, had been added to the ice-cold water instead of the metal.

He then calculated what the temperature of the mixture would have been, if, instead of the metal, a quantity of water of the same temperature with it, and equal to the metal in *bulk*, had been added to the ice-cold water. As the weights of the ice-cold water and the metal are equal, their volumes are inversely as their specific gravities. Therefore the volume of ice-cold water is to a quantity of hot water equal in volume to the metal, as the specific gravity of the metal to that of the water. Let M $=$ volume of cold water, $m =$ volume of hot water, $g =$ specific gravity of the metal, $1 =$ specific gravity of water; then $m : M :: 1 : g$; hence $m = \frac{M}{g} =$ (M being made $= 1$) $\frac{1}{g}$. Substituting this value of m in the formula, $\frac{MC + mc}{M + m} = x$, in which $M = 1$ and $C = 32$, x will be $=$ $\frac{32g + c}{g + 1}$. Therefore if the specific gravity of the metal be multiplied by 32, and the temperature of the metal be added, and the sum be divided by the specific gravity of the metal $+ 1$, the quotient will express the temperature to which the ice-cold water would be raised by adding to it a volume of water equal to that of the metal, and of the same temperature with it.

He then calculated how much water at the temperature of the metal it would take to raise the ice-cold water the same number of degrees which the metal had raised it. Let the temperature to which the metal had raised the ice-cold water be $= N$, if in the formula $\frac{MC + mc}{M + m} = x$, x be made $= N$, $M = 1$, $C = 32$, m will be $= \frac{N - 32}{c - N}$. Therefore if from the temperature to which the ice-cold water was raised by the metal 32 be subtracted, and if from the temperature of the metal be subtracted the temperature to which it raised the water, and the first remainder be divided by the last, the quotient will express the quantity of water of the temperature of the metal which would have raised the ice-cold water the same number of degrees that the metal did.

ifferent temperatures. These were published in his *Treatise on Heat.* In the first edition many errors had

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Now $\frac{N-32}{c-N}$ expresses the specific caloric of the metal, that of water eing $=$ 1. For (neglecting the small difference occasioned by the diffeence of temperature) the weight and volume of the ice-cold water are to he weight and volume of the hot water as 1 to $\frac{N-32}{c-N}$, and the numer of particles of water in each are in the same proportion. But the etal is equal in weight to the ice-cold water; it must therefore contain s many particles of matter; therefore the quantity of matter in the metal ust be to that in the hot water as 1 to $\frac{N-32}{c-N}$. But they gave out e same quantity of caloric; which, being divided equally among their articles, gives to each particle a quantity of caloric inversely as the bulks f the metal and water; that is, the specific caloric of the water is to that f the metal as 1 to $\frac{N-32}{c-N}$ *.

It will now be proper to give a specimen or two of his experiments, nd the calculations founded on them, as above described.

GOLD. *Specific gravity* 19.040.

Number of experiments.	Temperature of the metal.	Temperature to which the metal raised the water at 32°.	Temperature to which it would have been raised by a quantity of water equal in weight and heat to the metal.	Temperature to which it would have been raised by water equal in bulk and temperature to the metal.	Denominator of the fraction $\frac{N-32}{c-N} = \frac{1}{\frac{c-N}{N-32}}$ the numerator being 1.
1	163.4°	38.3°	97.7°	38.555°	19.857
2	144.5	37.4	88.25	37.58	19.833
3	127.4	36.5	79.7	36.68	20.500
4	118.4	36.05	75.2	36.15	20.333
5	103.1	35.6	65.75	35.42	18.750
6	5	34.45	63.5	35.06	19.000

Mean 19.712

* All these formulas have been altered to make them correspond with

crept into his deductions, from his not attending to the chemical changes produced by mixing many of the subjects of his experiments. These were corrected by his

LEAD. *Specific gravity* 11.456.

Number of experiments.	Temperature of the metal.	Temperature to which the metal raised the water at 32°.	Temperature to which the water would have been raised by a quantity of water equal in weight and heat to the metal.	Temperature to which the water would have been raised by water equal in bulk and temperature to the metal.	Denominator of the fraction $\frac{1}{\frac{c-N}{N-32}}$
1	186.8°	38.3°	109.4°	44.425°	23.571
2	181.40	37.85	106.7	43.473	24.538
3	165.2	37.4	98.6	42.692	23.666
4	163.4	37.4	97.7	42.548	23.333
5	136.4	36.5	84.2	40.344	22.200
6	131	36.05	81.5	39.947	24.700
7	126.5	36.05	79.25	39.585	22.333
8	107.6	35.15	69.8	38.339	23.000
9	94.1	34.7	63.05	36.985	22.000

Mean 23.515.

It is needless to add, that the last column marks the denominator of the specific caloric of the metal; the numerator being always 1, and the specific caloric of water being 1. Thus the specific caloric of gold is $\frac{1}{19.712}$. In exactly the same manner, and by taking a mean of a number of experiments at different temperatures, did Mr Wilcke ascertain the specific caloric of a number of other bodies.

Fahrenheit's thermometer. They are a good deal simpler when the experiments are made with Celsius's thermometer, as Mr Wilcke did. In it the freezing point is zero; and consequently, instead of 32 in the formula, 0 is always substituted.

ubsequent experiments, and the corrections inserted in is second edition. The method which he employed vas essentially the same with that which had been first uggested by Dr Black. Two substances of different emperatures were mixed uniformly; and the change f temperature produced on each by the mixture was onsidered as inversely proportional to its specific caoric *.

Several experiments on the specific caloric of bodies vere made also by Lavoisier and Laplace, which, from he well-known accuracy of these philosophers, cannot ut be very valuable.

Their method was exceedingly simple and ingenious; was first suggested by Mr Laplace. An instrument vas contrived, to which Lavoisier gave the name of *caorimeter*. It consists of three circular vessels nearly incribed into each other, so as to form three different apartments, one within the other. These three we shall all the *interior*, *middle*, and *external cavities*. The inerior cavity *ffff* (see section of the instrument fig. 11.) nto which the substances submitted to experiment are ut, is composed of a grating or cage of iron wire, suported by several iron bars. Its opening or mouth LM

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* The specific caloric of water being considered as 1, the formula was as follows: Let the quantity of water (which usually constituted one of he substances mixed) be W, and its temperature w. Let the quantity f the other body, whose specific caloric is to be ascertained, be B, and its temperature b. Let the temperature after mixture be m. The specific caloric of B is $\frac{W \times \overline{m - w}}{B \times \overline{b - m}}$; or, when the water is the hotter of the bodies mixed, the specific caloric of B is $\frac{W \times \overline{w - m}}{B \times \overline{m - b}}$. See Black's *Lectures*, i. 506.

is covered by the lid HG, which is composed of the same materials. The middle cavity *bbbb* is filled with ice. This ice is supported by the grate *m m*, and under the grate is placed a sieve. The external cavity *aaaa* is also filled with ice. We have remarked already, that no caloric can pass through ice at 32°. It can enter ice, indeed, but it remains in it, and is employed in melting it. The quantity of ice melted, then, is a measure of the caloric which has entered into the ice. The exterior and middle cavities being filled with ice, all the water is allowed to drain away, and the temperature of the interior cavity to come down to 32°. Then the substance, the specific caloric of which is to be ascertained, is heated a certain number of degrees, suppose to 212°, and then put into the interior cavity enclosed in a thin vessel. As it cools, it melts the ice in the middle cavity. In proportion as it melts, the water runs through the grate and sieve, and falls through the conical funnel *ccd* and the tube *x*) into a vessel placed below to receive it. The external cavity is filled with ice, in order to prevent the external air from approaching the ice in the middle cavity and melting part of it. The water produced from it is carried off through the pipe ST. The external air ought never to be below 32°, nor above 41°. In the first case, the ice in the middle cavity might be cooled too low; in the last, a current of air through the machine, and carries off some of the caloric. By putting various substances at the same temperature into this machine, and observing how much ice each of them melted in cooling down to 32°, it was easy to ascertain the specific caloric of each. Thus if water, in cooling from 212° to 32°, melted one pound of ice, and mercury 0 31 of a pound; the specific caloc of water was one, and that of mercury 0.31. This ppears by far the simplest method of making experi- ents on this subject; and must also be the most ac- ırate, provided we can be certain that all the melted ıow falls into the receiver. But from an experiment Mr Wedgewood, one would be apt to conclude that ıis does not happen. He found that the melted ice, far from flowing out, actually *froze* again, and choak- l up the passage.

A Table of the specific caloric of various bodies was kewise drawn up by Mr Kirwan, and published by lagellan in his Treatise on Heat. Mr Meyer has late- published a set of experiments on the specific caloric dried woods.

The result of all these investigations is exhibited in ne view in the following TABLE, which contains the pecific caloric of those bodies on which experiments ave hitherto been made.

I have added to it a column, expressing the specific aloric of equal bulks of the same bodies; which is the nly way of considering this subject in which the phrase *ipacity for caloric* is intelligible. This column was ormed by multiplying the specific caloric of equal reights of the various substances into their respective pecific gravities.

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TABLE *of the Specific Caloric of various Bodies, that of Water being* = 1.0000 ††.

Bodies.	Specific Gravity.	Specific Caloric	
		of equal Weights.	of equal Volumes.
I. GASES *.			
Hydrogen gas	0.000094	21.4000	0.00116
Oxygen gas	0.0034	4.7490	0.016146
Common air	0.00122	1.7900	0.002183
Carbonic acid gas	0.00183	1.0459	0.001930
Steam		1.5500	
Azotic gas	0.00120	0.7036	0.000844
II. LIQUIDS.			
Water	1.0000	1.0000	1.0000
Carbonat of ammonia †		1.851	
Arterial blood *		1.030	
Cows milk *	1.0324	0.9999	1.0322
Sulphuret of ammonia †	0.818	0.9940	0.8131
Venous blood *		0.8928	
Solution of brown sugar †		0.8600	
Nitric acid ‡		0.844	
Sulphat of magnesia 1 Water 8 †		0.844	
Common salt 1 Water 8 †		0.832	
Nitre 1 Water 8 ‡		0.8167	
Muriat of ammonia 1 Water 1.5 †		0.779	

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†† The specific caloric of the substances marked * was ascertained by Dr Crawford, those marked † by Mr Kirwan, ‡ by Lavoisier and La Place, ** by Wilcke, ‖ by Count Rumford. § Is the mean of Crawford, Kirwan, and Lavoisier; ¶ mean of Lavoisier and Kirwan; (*c*) mean of Crawford and Lavoisier; (*d*) mean of Wilcke and Crawford; (*e*) mean of Wilcke, Crawford, and Kirwan; (*f*) Meyer.

Chap. II.

TABLE *continued.*

Bodies.	Specific Gravity.	Specific Caloric of equal Weights.	of equal Volumes.
tar 1 ter 237.3 } † . . .		0.765	
ıtion of potass † . .	1.346	0.759	1.0216
ɔhat of iron 1 ter . . . . . 2.5 } †		0.734	
ɔhat of soda 1 ter . . . . 2.9 } †		0.728	
of olives †	0.9153	0.710	0.6498
monia †	0.997	0.7080	0.7058
iatic acid †	1.122	0.6800	0.7630
huric acid 4 er . . . . 5 } ‡		0.6631	
n 1 er 4.45 } †		0.649	
ic acid $9\frac{1}{3}$ e . . . 1 } ‡		0.6181	
e 1 ter 3 } †		0.646	
hol *	0.8371	0.6021	0.5040
huric acid § . . .	1.840	0.5968	1.0981
ous acid †	1.355	0.576	0.7804
eed oil †	0.9403	0.528	0.4965
maceti oil * . . .		0.5000	
of turpentine † . .	0.9910	0.472	0.4677
egar †		0.3870	0.3966
e 9 er 16 } ‡		0.3346	
cury ¶	13.568	0.3100	4.2061
illed vinegar † . .		0.1030	0.1039
III. SOLIDS.			
. . . .		0.9000	
ide with the hair *		0.787	
s of a sheep * . .		0.769	
. of ox-beef † . . .		0.7400	

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TABLE *continued.*

Bodies.	Specific Gravity.	Specific Caloric	
		of equal Weights.	of equal Volumes.
Pinus sylvestris (*f*) . .	0.408	0.65	0.2652
Pinus abies (*f*)	0.447	0.60	0.2682
Tilea Europæa (*f*) . .	0.408	0.62	0.2530
Pinus picea (*f*)	0.495	0.58	0.2871
Pyrus malus (*f*) . . .	0.639	0.57	0.3642
Betula alnus (*f*)	0.484	0.53	0.2565
Quercus robur sessilis (*f*)	0.531	0.51	0.2708
Fraxinus excelsior (*f*)	0.631	0.51	0.3218
Pyrus communis (*f*) .	0.603	0.50	0.3025
Rice *		0.5050	
Horse beans *		0.5020	
Dust of the pine tree *		0.5000	
Pease *		0.4920	
Fagus sylvatica (*f*) . .	0.692	0.49	0.3390
Carpinus betulus (*f*) .	0.690	0.48	0.3312
Betula alba (*f*)	0.608	0.48	0.2918
Wheat *		0.4770	
Elm (*f*)	0.646	0.47	0.3036
Quercus robur pedunculata (*f*)		0.45	0.3006
Prunus domestica (*f*)	0.668	0.44	0.3023
Diaspyrus ebenum (*f*)	0.687	0.43	0.4532
Barley *	1.054	0.4210	
Oats *		0.4160	
Pitcoal *		0 2777	
Charcoal *		0.2631	
Chalk *		0.2564	
Rust of iron *		0.2500	
White oxide of antimony washed *		0.2270	
Oxide of copper nearly freed from air * . . .		0.2272	
Quicklime (*c*)		0.2199	
Stoneware †		0.195	
Agate **	2.648	0.195	0.563

TABLE *continued.*

Bodies.	Specific Gravity.	Specific Caloric	
		of equal Weights.	of equal Volumes.
tal ‡	3.189 ?	0.1929	0.6152
ers *		0.1923	
ish glass** . . .	2.386	0.187	0.4461
s of cinders * . .		0.1885	
ur †	1.99	0.183	0.3642
glass †	3.3293	0.174	0.5793
of iron nearly freed n air *		0.1665	
e oxide of antimo- litto *		0.1666	
s of the Elm * . .		0.1402	
e of zinc nearly free n air *		0.1369	
(*d*)	7.876	0.1264	0.9955
(*d*)	8.358	0.1141	0.9536
er (*d*)	8.784	0.1121	0.9847
iron ‡		0.1099	
e of lead and tin *		0.102	
metal ‖		0.1100	
e oxide of tin near- ree from air * . .		0.0990	
(*d*)	7.154	0.0981	0.7018
s of charcoal * . .		0.0909	
**	10.001	0.082	0.8201
w oxide of lead near- eed from air * . .		0.0680	
e)	7.380	0.0661	0.4878
nony (*d*)	6.107	0.0637	0.3890
**	19.040	0.050	0.9520
(*e*)	11.456	0.0424	0.4857
uth **	9.861	0.043	0.4240

difference in the specific caloric of bodies is per- analogous to all other chemical combinations.

Specific caloric proportional to the affinity of bodies for heat.

Scarcely any two metals, for instance, when converted into oxides, combine with precisely the same quantity of oxygen. It depends therefore upon the affinity which exists between bodies and caloric. In all probability, indeed, the specific caloric of bodies is always proportional to their affinity for caloric; that is to say, the greater their affinity, the greater their specific caloric. For it is reasonable to suppose, that the greater the affinity between a body and caloric, the greater quantity of caloric will combine with it before it be in a disposition to part with caloric to other bodies; consequently the greater quantity of caloric will be necessary, in order to raise it to a given temperature.

If this reasoning be conclusive, it follows, that the specific caloric of bodies is always inversely as their conducting power. For it was shewn formerly, that the conducting power is inversely as the affinities of bodies for caloric. This conclusion is of considerable importance; not only because it simplifies the theory of the combinations of caloric with bodies, but because it enables us (if it be accurate) to determine the conducting power of bodies from their specific caloric, or the contrary. A set of experiments on purpose would be necessary to establish it completely. In the small number of bodies whose conducting powers I have ascertained, the numbers are more nearly the inverse of the specific calorics of these bodies as determined in the Table, than could have been expected in experiments of so delicate a nature. That this is the case, is evident from the following Table:

Bodies.	Specific Caloric.	Conducting Power. by Theory.	by Exper.	Difference.
ter	1	1	1	0
rcury . . .	0.31	3.22	4.600	+ 1.38
seed oil . .	0.9403	1.06	1,085	+ 0.02

is probable, then, that the conducting power of s is always inversely as their specific caloric. This enable us to form a pretty accurate notion of the ve conducting power of bodies, by inspecting the of their specific caloric.

THE ABSOLUTE QUANTITY OF CALORIC IN BODIES.

us we see that the relative quantity of caloric is different in different bodies, even when they are of ame temperature by the test of the thermometer. obvious, therefore, that the thermometer is not le of indicating the quantity of caloric contained in s; since, not to mention the specific caloric, the nce of the caloric which occasions fluidity is not ted by it at all. Thus steam at 212° contains ° more caloric than water at 212°, yet the tempe- of each is the same. Is there then any method certaining the absolute quantity of caloric which y contains? At what degree would a thermo- stand (supposing the thermometer capable of uring so low), were the body to which it is ap- totally deprived of caloric? or, what degree of ermometer corresponds to the real zero?

Hypothesis of Dr Irvine

first person, at least since men began to think tely on the subject, who conceived the possibility

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of determining this question, was Dr Irvine of Glasgow. He invented a theorem, in order to ascertain the real zero, which has, I know not for what reason, been ascribed by several writers to Mr Kirwan.

1. It is obvious, that if the specific caloric of bodies continues the same at all temperatures, the absolute quantity of caloric in bodies must be proportional to the specific caloric. Thus if the specific caloric of mercury be only the third of that of water, water must contain three times as much caloric as mercury of the same temperature. Let us suppose both bodies to be totally deprived of caloric, and that we apply to them a thermometer, the zero point of which indicates absolute cold or a total deprivation of heat. To raise the mercury and water one degree we must throw in a certain quantity of heat, and thrice as much heat will be necessary to produce the effect upon the water as on the mercury. To produce a temperature of two degrees the same rule must be observed; and so on for three, four, and any number of degrees. Thus at all temperatures the water would contain thrice as much caloric as the mercury.

2. This supposition that the specific caloric of bodies continues the same at all temperatures was the foundation of Dr Irvine's reasoning. He had ascertained, that when a body changes from a solid to that of a liquid, its specific caloric at the same time increases; and that the same increase is observable when a liquid is converted into an elastic fluid. The constancy of the specific caloric of bodies on which he founded his theory, was true only while they remained in the same state. He supposed likewise, that when a solid body is converted into a liquid, the caloric absorbed without any increase of temperature, or the latent heat, is merely the consequence

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e increase of the specific caloric of the body. Thus
1 ice is converted into water, 140° of caloric are
rbed, because the specific caloric of water is so much
ter than that of ice, as to require 140° additional of
ic to preserve the same temperature which it had
1 its specific caloric was less. The same supposition
unted for the absorption of caloric when liquids are
erted into elastic fluids.

Dr Irvine's theory of the absolute caloric of bodies
nded upon these two opinions, which he considered
st principles. The first gave him the ratio of the
lute calorics of bodies; the second, the difference
een two absolute calorics. Having these data, it
easy to calculate the absolute quantity of caloric in
body whatever. Thus let us suppose that the spe-
caloric of water is to that of ice as 10 to 9, and
when ice is converted into water the quantity of
ic absorbed is 140°. Let us call the absolute quan-
of caloric in ice at 32° x, it is obvious that the ab-
e caloric in water at 32 is $= x + 140^\circ$. We have
the absolute caloric of ice $= x$, that of water $= x$
40. But these quantities are to each other as 10 to
Therefore we have this proportion $10 : 9 :: x +$
$: x$. By multiplying the extremes and means we
his equation $10\,x = 9\,x + 1260$, from which we
ce $x = 1260$. Thus we obtain the absolute quan-
of caloric in ice of 32°, and find it to amount to
Water at 32° of course contains 1400 degrees of
ic.

Examined,

ch was the ingenious method proposed by Dr Irvine
scertaining the real zero, or the degree at which a
nometer would stand when plunged into a body al-
her destitute of caloric. We see, that by the above

calculation it would be with regard to ice 1260 degrees below 32° of Fahrenheit's scale, or 1228 degrees below 0. Dr Crawford, however, who made his experiments upon a different set of bodies, places the real zero at 1500° below 0° of Fahrenheit.

And found insufficient.

4. Unfortunately the truth of the principles on which this theory of Dr Irvine is founded is by no means established. The first proposition, that the specific caloric of bodies continues the same at all temperatures has by no means been ascertained by experiments ; so far from it, that the very contrary has been proved by Dr Irvine himself to hold in the case of spermaceti and wax. But even if it did hold at all temperatures while bodies continue in the same state ; still as every change of state is confessedly attended with a corresponding change of specific caloric, we have no right to affirm that the specific caloric is proportional to the absolute caloric. For instance, though the specific caloric of ice be to that of water as 9 to 10, it does not follow that their absolute calorics bear the same proportion ; nor can any reason be assigned for supposing that this ratio ought to hold.

5. The second proposition, namely, that the caloric absorbed by a body, during its change of state, is merely owing to the change of the specific caloric of the body, is equally unsupported by proof: indeed it is directly contradicted by experiment. If the specific caloric of bodies has any meaning at all, it can only be, that the same quantity of caloric raises the temperature of one body a greater number of degrees than it does another. When we say that the specific caloric of A is = 6, and that of B = 1, what do we mean, unless that the quantity of caloric which raises B 6° raises A only 1°, or that what raises B 60° or 600°, raises A

10° or 100°? When we say that the specific calo-
water is 10, and that of ice 9, do we not mean,
he quantity of caloric which raises the ice 10° or
, raises water only 9° or 90°? Yet during the
ge of ice into water, 140° of caloric enter it with-
raising its temperature; a quantity greater than
can be accounted for by the difference of specific
ic by 126 degrees. The quantity that disappears,
fore, is *not* proportional to the difference of specific
ic; and consequently any theory which depends on
supposition cannot be well-founded. When water
nverted into steam, 1000° of caloric disappear; yet
pecific caloric of steam is to that of water, accord-
o Dr Crawford's own experiments, only as 155 to
so that no less than 483 degrees disappear, which
ot be accounted for according to this theory.

ne two opinions upon which Dr Irvine's theory is
being both of them unfounded, the theory it-
nust be given up as totally unsupported by expe-
e. Accordingly if we compare together the re-
obtained by various experiments, we shall find
there is not the smallest correspondence between
. If the real zero has any meaning at all, it must
fy the degree to which the thermometer (suppo-
it could be used) would sink on being applied to a
which contained no heat. It must therefore be a
point; and were the theorem which we are exa-
ng well founded, experiments upon every different
tance, if conducted with accuracy, would lead to the
result. Let us see whether this be the case.

om Dr Crawford's experiments, it follows, as we
seen, that the real zero is 1500° below 0.

Mr Kirwan, from comparing the specific caloric of water and ice, fixed the real zero at 1318° below 0.

From the experiments of Lavoisier and La Place on a mixture of water and quicklime, in the proportion of 9 to 16, it follows, that the real zero is 3426° below 0.

From their experiments on a mixture of 4 parts of sulphuric acid and 3 parts of water, it follows, that the real zero is 7260° below 0.

Their experiments on a mixture of 4 parts of sulphuric acid and 5 of water place it at 2598° below 0.

Their experiments on $9\frac{1}{3}$ parts of nitric acid and 1 of lime, place it at $\frac{1889}{-0.01783}$ below $32°, = +23837°$*.

These results differ from one another so enormously, and the last of them, which places the real zero far above a red heat, is so absurd, that they are alone sufficient to convince us that the data on which they are founded are not true.

Mr Dalton's hypothesis,

6. Another method of determining the absolute quantity of caloric in bodies has been lately proposed by Mr Dalton†, a philosopher whose ingenuity and sagacity leave him inferior to none that have hitherto turned their attention to this difficult subject. He supposes that the repulsion which exists between the particles of elastic fluids is occasioned by the caloric with which these particles are combined, and that it is always proportional to the absolute quantity of caloric so combined. Now the diameter of the sphere over which the

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* See Seguin, *Ann. de Chim.* v. 231.

† *Manchester Memoirs*, v.

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nce of a particle extends, is the measure of the
sion, and it is proportional to the cube root of the
mass. The repulsion exerted by the particles of
stic fluid, at different temperatures, is proportion-
the cube root of the bulk of the fluid in these tem-
ures. Therefore, according to this hypothesis, the
ute quantity of caloric in elastic fluids, at different
eratures, is proportional to the cube roots of these
at these temperatures. To give an example:
bulk of air at 55° being 1000, its bulk at 212° is
; therefore the absolute heat in air at 55° is to its
at 212° as $\sqrt[3]{1000}$ to $\sqrt[3]{1325}$, or nearly as 10 to
Let us call the absolute heat of air at 55° x; then
osolute heat of air at 212° is $x + 157$. This gives
e following proportion; $10 : 11 :: x : x + 157$.
e $11x = 10x + 1570$, and $x = 1570$. Thus we ob-
570 for the absolute heat in air at 55°. Subtract-
hese 55 degrees, we have 1515° below 0 for the
of real zero *.

ch is the hypothesis of Mr Dalton; and the result
h he obtained corresponds pretty nearly with Dr
ford's deductions from some of his experiments:
f it be applied to other temperatures, no such ex-
oincidence will be observed, as has been very well
n by an anonymous writer in Nicholson's *Journal* †.
pears from the examples there produced, that the
er the temperature at which the comparison is made,
ower is the point obtained for the commencement
e scale of heat. But Mr Dalton has rendered it
able that this is owing to the thermometer not be-

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* *Manchester Memoirs*, v. 601.

† 1803, vol. iv. 223.

ing an accurate measure of the scale of temperature *; for when the temperature is corrected by Deluc's experiments, the anomaly in one of the instances disappears.

Insufficient.

This hypothesis of Mr Dalton is founded on a supposition which, though it cannot be demonstrated, is nevertheless exceedingly probable to a certain extent: for if elastic fluids owe their peculiar fluidity to heat, and if their increase of elasticity be proportional to their increase of heat, I do not see how it can be denied that the repulsion between the particles of these bodies is proportional to the caloric combined with them: not, however, to the whole of their caloric, but to that portion of it only which occasions their elasticity, and which increases their elasticity. It is at present believed that the abstraction of heat is capable of converting elastic fluids into liquids, and even into solids. Mr Dalton himself is a supporter of this opinion, which, in the present state of our knowledge, scarcely admits of dispute. But the particles of liquids and solids do not repel one another, but possess a contrary property; they attract one another; yet they all confessedly contain a great deal of heat. Were we then to convert elastic fluids into liquids, by abstracting heat from them, we would deprive their particles of the repulsive force which they exert, and yet leave a considerable quantity of caloric in them. It is not the whole of the caloric, then, which is combined with the particles of elastic fluids, that occasions their repulsion, but only a part of it. Now surely it will not be said, that the

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* Nicholson's *Journal*, 1803, v. 34.

lsive force of the particles of elastic fluids is pro-
ional to that caloric which has no effect in produ-
the repulsion, and which would remain in combi-
n, though that repulsion were annihilated. It can
be proportional to that portion of the caloric
h occasions repulsion. Mr Dalton's hypothesis,
only enables us to find out the quantity of calo-
hich occasions the elastic fluidity of the bodies in
ion, and by no means the whole of the caloric
h they contain, unless they were supposed to con-
in the state of elastic fluids till deprived of all the
vhich they contain except the last particle: which
upposition that cannot be made. It does not even
ıs any precise notion of the caloric of elastic flui-
unless we ascertain the specific caloric of the body
estion; and after we have done so, reduce the de-
of caloric of fluidity to a known standard, as to
ımber of degrees which they would raise the tem-
ıre of water, supposing it not to change its state.
indeed is absolutely necessary in all cases when we
o speak definitely of the real zero: For as more
s necessary to raise one body a certain number of
s than to produce the same change on another,
se we were to deprive these bodies altogether of
and then to raise them both to a certain tempera-
he number of degrees of heat added to both would
ıal; yet the absolute quantity of heat added to
vould be very unequal. The term real zero can
ıo meaning whatever, as far as it alludes to the
ty of heat in bodies, unless we always refer to
particular body, as water, and make it our stand-

Thus it appears that none of the methods hitherto proposed are insufficient to enable us to discover the quantity of heat in bodies. At the same time, I have not the smallest doubt, from the known sagacity and precision of Mr Dalton, that much curious and important information will result from his farther prosecution of the subject.

III. Of Cold.

Having pointed out the methods of ascertaining the relative quantity of heat in bodies of the same temperature, and pointed out the various hypotheses respecting their absolute heats, it remains for us only to make a few observations on the abstraction of heat from bodies, or on what in common language is called *cold*.

Sensations of heat and cold explained.

When caloric combines with our own bodies, or separates from them, we experience, in the first case, the sensation of *heat;* in the second, of *cold*. When I put my hand upon a hot iron, part of the caloric leaves the iron, and enters my hand; this produces the sensation of heat. On the contrary, when I put my hand upon a lump of ice, the caloric rapidly leaves my hand, and combines with the ice; this produces the sensation of cold. The sensation of heat is occasioned by caloric passing into our bodies; the sensation of cold by caloric passing out of our bodies. We say that a body is hot when it communicates caloric to the surrounding bodies; we call it cold when it absorbs caloric from other bodies. The strength of the sensations of heat and cold depends upon the rapidity with which the caloric enters or leaves our bodies; and this rapidity is

portional to the difference of the temperature be-
:en our bodies and the hot or cold substance, and to
conducting power of that substance. The higher
temperature of a body is, the stronger a sensation
ieat does it communicate; and the lower the tem-
ıture, the stronger a sensation of cold: and when
temperature is the same, the sensations depend up-
he conducting power of the substance.

'hus what in common language is called *cold*, is no-
g else than the absence of the usual quantity of ca-
:. When we say that a substance is *cold*, we mean
ely that it contains less caloric than usual, or that its
perature is lower than that of our bodies.

Cold ascribed to frigorific particles.

here have been philosophers, however, who main-
:d that cold is produced, not by the abstraction of
ric merely, but by the addition of a positive some-
g, of a peculiar body endowed with specific quali-
This was maintained by Muschenbroeck and De
ran, and seems to have been the general opinion of
osophers about the commencement of the 18th cen-
. According to them, cold is a substance of a sa-
ıature, very much resembling nitre, constantly float-
n the air, and wafted about by the wind in very
ıte corpuscles, to which they gave the name of *fri-
ic particles*.

Their existence disproved.

hey were induced to adopt this hypothesis, because
could not otherwise account for the freezing of wa-
According to them, these frigorific particles insi-
e themselves like wedges between the molecules of
r, destroy their mobility, and thus convert water
ice. Dr Black, by discovering the cause of the
ing of water, banished the frigorific particles from
egions of philosophy; because the advocates for

them never brought any other proof for their existence than the convenience with which they accounted for certain appearances. Of course, as soon as these appearances were explained, without their use, every reason for supposing their existence was destroyed.

Apparent reflection of cold.

The only fact which gives any countenance to the opinion that cold is a body, has been furnished by the following very curious experiment of Mr Pictet*. Two concave tin mirrors being placed at the distance of 10½ feet from each other, a very delicate air thermometer was put into one of the foci, and a glass matrass full of snow into the other. The thermometer sunk several degrees, and rose again when the matrass was removed. When nitric acid was poured upon the snow (which increases the cold), the thermometer sunk 5° or 6° lower. Here *cold* seems to have been emitted by the snow, and reflected by the mirrors to the thermometer, which could not happen unless cold were a substance. The experiment is certainly highly interesting, and deserving a more accurate examination than has been hither-

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* This experiment, or at least a similar one, was made long ago, and is found in the Essays of the Academy del Cimento, translated by Waller in 1684, p. 103. The ninth experiment, of reflected cold, is thus related. "We were willing to try, if a concave glass, set before a mass of 500 lbs. of ice, made any sensible repercussion of cold, upon a very nice thermometer of 400 degrees, placed in its focus. The truth is, it immediately began to subside; but, by reason of the nearness of the ice, it was doubtful whether the direct or reflected rays of cold were more efficacious: upon this account, we thought of covering the glass, and (whatever may be the cause) the spirit of wine did indeed presently begin to rise: for all this, we dare not be positive but there might be some other cause thereof, besides the want of the reflection from the glass, since we were deficient in making all the trials necessary to clear the experiment." See *Journals of the Royal Institution*, i. 224.

estowed on it. In order to explain it, we must re-
ect that caloric is constantly radiating from all bo-
. It is evident that the temperature of the thermo-
er, like that of all other bodies, is maintained part-
y the irradiation of caloric from the surrounding bo-
. It must therefore, since it is placed in the focus
ne of the mirrors, be affected by whatever body is
ed in the focus of the other. If that body be cold-
han the surrounding bodies, less caloric will be ir-
ated from it and thrown upon the thermometer;
sequently the thermometer will be depressed till the
iency is supplied by some other channel. Such
ly is the explanation of this singular fact offered
Prevost and Dr Hutton; but it cannot be denied
this explanation, ingenious as it is, is very far from
g satisfactory.

very great degree of cold may be produced by
ing together different solids, which suddenly become
id. The cause of this has been already explained.
t as such mixtures are often employed in chemistry,
rder to be able to expose bodies to the influence of
w temperature, it will be worth while to enumerate
different substances which may be employed for
purpose, and the degree of cold which each of them
apable of producing.

Of freezing mixtures.

The first person who made experiments on freezing
tures was Fahrenheit. But the subject was much
re completely investigated by Mr Walker in a paper
lished in the Philosophical Transactions for 1795.
ce that time several curious additions have been
le by Professor Lowitz, particularly the introduction
nuriat of lime, which produces a very great degree

of cold when mixed with snow*. The experiments of Lowitz have been lately repeated and extended by Mr Walker †. The result of all these experiments may be seen in the following TABLE:

TABLE *of Freezing Mixtures.*

Mixtures.	Thermometer sinks.
Muriat of ammonia . . 5 parts Nitre . . . . 5 Water 16	From 50° to 10°
Muriat of ammonia . . 5 Nitre . . . . 5 Sulphat of soda . . . 8 Water 16	From 50 to 4
Nitrat of ammonia . . 1 Water 1	From 50 to 4
Nitrat of ammonia . . 1 Carbonat of soda . . . 1 Water 1	From 50 to 7
Sulphat of soda . . . . 3 Diluted nitric acid . . 2	From 50 to 3
Sulphat of soda . . . . 6 Muriat of ammonia . . 4 Nitre . . . . 2 Diluted nitric acid . . 4	From 50 to 10
Sulphat of soda . . . 6 Nitrat of ammonia . . 5 Diluted nitric acid . . 4	From 50 to 14

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* *Ann. de Chim.* xxii. 297, and xxix. 281.

† *Phil. Trans.* 1801, p. 120.

TABLE *of Freezing Mixtures continued.*

Mixtures.	Thermometer sinks.
hosphat of soda . . . 9 parts iluted nitric acid . . 4	From 50° to 12°
hosphat of soda . . . 9 itrat of ammonia . . 6 iluted nitric acid . . 4	From 50 to 21
ulphat of soda . . . . 8 uriatic acid 5	From 50 to 0
ulphat of soda . . . . 5 iluted sulphuric acid 4	From 50 to 3
now . . . . 1 ommon salt 1	From 32 to 0
uriat of lime . . . . 3 now 2	From 32 to —50
otass . . . . 4 now 3	From 32 to —51
now . . . . 1 iluted sulphuric acid 1	From 20 to —60
now or pounded ice 2 ommon salt. 1	From 0 to —5
now and diluted nitric acid	From 0 to —46
uriat of lime . . . . 2 now 1	From 0 to —66
now or pounded ice 1 ommon salt . . . . . 5 uriat of ammonia and nitre 5	From —5 to —18

TABLE *of Freezing Mixtures continued.*

Mixtures.	Thermometer sinks.
Snow . . . . 2 Diluted sulphuric acid 1 Diluted nitric acid . . 1	From —10° to —56°
Snow or pounded ice 12 Common salt . . . . 5 Nitrat of ammonia . . 5	From —18 to —25
Muriat of lime . . . . 3 Snow 1	From —40 to —73
Diluted sulphuric acid 10 Snow 8	From —68 to —91

In order to produce these effects, the salts employed must be fresh crystallized, and newly reduced to a very fine powder. The vessels in which the freezing mixture is made should be very thin, and just large enough to hold it, and the materials should be mixed together as quickly as possible. The materials to be employed in order to produce great cold ought to be first reduced to the temperature marked in the Table, by placing them in some of the other freezing mixtures; and then they are to be mixed together in a similar freezing mixture. If, for instance, we wish to produce a cold = — 46°, the snow and diluted nitric acid ought to be cooled down to 0°, by putting the vessel which contains each of them into the 12th freezing mixture in the above Table, before they are mixed together. If a still greater cold is required, the materials to produce it are to be brought to the proper temperature by being preusly placed in the second freezing mixture. This cess is to be continued till the required degree of l has been procured *.

SECT. VI.

OF THE SOURCES OF CALORIC.

AVING in the preceding Sections examined the na- e, properties, and effects of caloric, as far as the sub- has been hitherto investigated, it now only remains us to consider the different methods by which calo- may be evolved or made sensible, or the different rces from which it may be obtained. These sources y be reduced to five: It *radiates* constantly from sun; it is evolved during combustion; and it is ex- ated in many cases by percussion, friction, and mix- e. The sources of heat, then, are the *sun*, *combus- , percussion*, *friction*, *mixture*. Let us consider each hese sources in the order in which we have enume- d them.

FIRST SOURCE.

THE SUN.

HE sun, which constitutes as it were the vital part he whole solar system, is an immense globe, whose

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* Walker, *Phil. Trans.* 1795.

Nature of the sun.

diameter has been ascertained by astronomers to be no less than 883,246 miles, and which contains about 333,928 times as much matter as the earth. Philosophers long supposed that this immense globe of matter was undergoing a violent combustion; and to this cause they ascribed the immense quantity of light and heat which are constantly separating from it. But the late very curious and important observations of Dr Herschel leave scarcely any room for doubting that this opinion is erroneous *. From these observations it follows, that the sun is a solid opaque globe, similar to the earth or other planets, and surrounded by an atmosphere of great density and extent. In this atmosphere there float two regions of clouds: The lowermost of the two is opaque and similar to the clouds which form in our atmosphere; but the higher region of clouds is luminous, and emits the immense quantity of light to which the splendour of the sun is owing. It appears, too, that these luminous clouds are subject to various changes both in quantity and lustre. Hence Dr Herschel draws as a consequence, that the quantity of light and heat emitted by the sun varies in different seasons. And he supposes that this is one of the chief sources of the difference between the temperatures of different years.

Emits three species of rays.

1. From the experiments of Herschel, Bockman, and Wollaston, it follows that the sun emits three kinds of rays; namely, *calorific*, *colorific*, and *deoxidizing*. The first occasions *heat*, the second *colour*, and the third separates oxygen from various bodies.

2. When the solar rays strike transparent bodies, they

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* *Phil. Trans.* 1801. p. 265.

These rays heat opaque bodies in proportion to the darkness of their colour.

uce very little effect; but opaque bodies are heated
em. Hence it follows that transparent bodies al-
these rays to pass through them; but that they are
ned, at least in part, by opaque bodies. The deep-
e colour of the opaque body, the greater is the rise
mperature which it experiences from exposure to
sun's rays. It has been long known, that when co-
ed bodies are exposed to the light of the sun or of
ɔustible bodies, their temperature is raised in pro-
on to the darkness of their colour. To ascertain
point, Dr Hooke made a curious set of experiments,
h were repeated long after by Dr Franklin. This
sopher exposed upon snow pieces of cloth of diffe-
colours (white, red, blue, black) to the light of the
and found that they sunk deeper, and consequently
ired heat, in proportion to the darkness of their co-
This experiment has been repeated with more
ision by Mr Davy. He exposed to the light six
l pieces of copper painted white, yellow, red, green,
, and black, in such a manner that only one side of
ieces was illuminated. To the dark side of each
attached a bit of cerate, which melted when heated
°. The cerate attached to the blackened copper
me first fluid, that attached to the blue next, then
attached to the green and red, then that to the yel-
and last of all that attached to the white *. Now
well known that dark-coloured bodies, even when
lly exposed to the light, reflect less of it than those
h are light-coloured. But since the same quantity
upon each, it is evident that dark-coloured bodies

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* Beddoes's *Contributions*, p. 4.

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Division II.

must absorb and retain more of it than those which are light-coloured. That such an absorption actually takes place is evident from the following experiment. Mr Thomas Wedgewood placed two lumps of luminous or phosphorescent marble on a piece of iron heated just under redness. One of the lumps of marble which was blackened over gave out no light; the other gave out a great deal. On being exposed a second time in the same manner, a faint light was seen to proceed from the clean marble, but none at all could be perceived to come from the other. The black was now wiped off, and both the lumps of marble were again placed on the hot iron: The one that had been blackened gave out just as little light as the other *. In this case, the light which ought to have proceeded from the luminous marble disappeared: it must therefore have been stopped in its passage out, and retained by the black paint. Now black substances are those which absorb the most light, and they are the bodies which are most heated by exposure to light. Cavallo observed, that a thermometer with its bulb blackened stands higher than one which had its bulb clean, when exposed to the light of the sun, the light of day, or the light of a lamp †. Mr Pictet made the same observation; and took care to ascertain, that when the two thermometers were allowed to remain for some time in a dark place, they acquired precisely the same height. He observed, too, that when both thermometers had ben raised a certain number of degrees, the clean one fell a good deal faster than the other ‡.

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* *Phil. Trans.* 1792.

† Ibid. 1780.

‡ *Sur le Feu*, chap. iv.

Heat produced by the rays of the sun,

The temperature produced in bodies by the direct
n of the sun's rays seldom exceeds 120°; but a
higher temperature would be produced if we
to prevent the heat communicated from being car-
off by the surrounding bodies. Mr Saussure made
tle box lined with fine dry cork, the surface of
h was charred to make it black and spongy, in or-
hat it might absorb the greatest possible quantity
e sun's rays, and be as bad a conductor of caloric
ossible. It was covered with a thin glass plate.
n this box was set in the sun's rays, a thermometer
in the bottom of it rose in a few minutes to 221°;
the temperature of the atmosphere was only
*. Professor Robison constructed an apparatus of
same kind, employing three very thin vessels of
glass, which transmit more caloric than any of the
species of glass. They were of the same shape,
ed above, with an interval of ¼ inch between them.
y were set on a cork base prepared like Saussure's,
placed on down contained in a pasteboard cylinder.
h this apparatus the thermometer rose often in a
summer day to 230°, and once to 237°. Even
n set before a bright fire, the thermometer rose to
° †.

By burning glasses.

Such is the temperature produced by the direct
of the sun. But when its rays are concentrated
burning glass, they are capable of setting fire to

Voyages sur les Alpes, ii. 932.

Black's *Lectures*, i. 547. When the apparatus was carried to a damp
before the glasses were put in their places, so that the air within
noist, the thermometer never rose above 208°. Hence Dr Robison
uded that moist air conducts better than dry; a conclusion fully
rmed by the subsequent experiments of Count Rumford.

combustibles with ease, and even of producing a temperature at least as great, if not greater, than what can be procured by the most violent and best conducted fires. In order to produce this effect, however, they must be directed upon some body capable of absorbing and retaining them; for when they are concentrated upon transparent bodies, or upon fluids, mere air for instance, they produce little or no effect whatever.

5. These facts, which have been long known, induced philosophers to infer, that the fixation of light in bodies always raises their temperature. On the other hand, it was known that the fixation of a certain quantity of caloric always occasions the appearance of light; for when bodies are raised to a certain temperature they always become red hot. Hence it was concluded that light and caloric reciprocally evolve each other; and this was explained by supposing that they have the property of repelling each other.

Owing to the fixation of caloric.

6. But the recent discoveries in this part of chemistry have destroyed all the evidences on which these conclusions were drawn. Not only light but caloric also radiates from the sun. We cannot therefore ascribe the rise of temperature to the absorption of light, but to the absorption of caloric; especially as the rays of the moon, though luminous, occasion no rise of temperature. The facts, then, oblige us to conclude, that the sun emits rays of caloric; that these rays are absorbed by opaque bodies, and detained by them; and that the absorption, other things being equal, is proportional to the darkness of the colour of the absorbing body. Thus it appears, that when a body is acted on by rays of caloric, the change of temperature depends upon its opacity and colour. In this respect caloric agrees with light. But

n caloric is *conducted* to a body, its opacity or colour
not influence the subsequent change of tempera-

SECOND SOURCE.

COMBUSTION.

Phenomena of combustion.

HERE is perhaps no phenomenon more wonderful
self, more interesting on account of its utility, or
ch has more closely occupied the attention of che-
s, than *combustion*. When a stone or a brick is
ed, it undergoes no change except an augmentation
emperature; and when left to itself, it soon cools
and becomes as at first. But with combustible
es the case is very different. When heated to a
ain degree in the open air, they suddenly become
h hotter of themselves, continue for a considerable
intensely hot, sending out a copious stream of ca-
and light to the surrounding bodies. This emis-
, after a certain period, begins to diminish, and at
ceases altogether. The combustible has now un-
one a most complete change; it is converted into a
tance possessing very different properties, and no
er capable of combustion. Thus when charcoal is
for some time at the temperature of about 800°, it
les, becomes intensely hot, and continues to emit
and caloric for a long time. When the emission
es, the charcoal has all disappeared, except an in-
iderable residuum of ashes; being almost entirely
erted into carbonic acid gas, which makes its escape
ss the experiment be conducted in proper vessels.
be collected, it is found to exceed greatly in weight
whole of the charcoal consumed.

1. The first attempt to explain combustion was crude and unsatisfactory. A certain elementary body, called *fire*, was supposed to exist, possessed of the property of devouring certain other bodies, and converting them into itself. When we set fire to a grate full of charcoal, we bring, according to this hypothesis, a small portion of the element of fire, which immediately begins to devour the charcoal, and to convert it into fire. Whatever part of the charcoal is not fit for being the food of fire is left behind in the form of ashes.

Hooke's theory of combustion.

2. A much more ingenious and satisfactory hypothesis was proposed in 1665 by Dr Hooke. According to this extraordinary man, there exists in common air a certain substance, which is like, if not the very same with that which is fixed in saltpetre. This substance has the property of dissolving all combustibles; but only when their temperature is considerably raised. The solution takes place with such rapidity, that it occasions both heat and light; which in his opinion are mere motions. The dissolved substance is partly in the state of air, partly coagulated in a liquid or solid form. The quantity of this solvent present in a given bulk of air is incomparably less than in the same bulk of saltpetre. Hence the reason that a combustible continues burning but for a short time in a given bulk of air: The solvent is soon saturated, and then of course the combustion is at an end. Hence also the reason that combustion succeeds best when there is a constant supply of fresh air, and that it may be greatly accelerated by forcing in air with bellows *.

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* Hooke's *Micrographia*, p. 103. See also his *Lampas*.

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Adopted by Mayow.

out ten years after the publication of Hooke's *Mi-*
aphia, his theory was adopted by Mayow, without
wledgment, in a tract which he published at Ox-
on saltpetre [*]. We are indebted to him for a
er of very ingenious and important experiments,
ich he anticipated several modern chemical philo-
rs; but his reasoning is for the most part absurd,
he additions which he made to the theory of Hooke
ceedingly extravagant. To the solvent of Hooke
ves the name of *spiritus nitro-aereus*. It consists,
pposes, of very minute particles, which are con-
y at variance with the particles of combustibles,
rom their quarrels all the changes of things pro-
Fire consists in the rapid motion of these parti-
heat in their less rapid motion. The sun is mere-
tro-aerial particles moving with great rapidity.
fill space. Their motion becomes more languid
ding to their distance from the sun; and when
approach near the earth, they become pointed, and
itute *cold* [†].

Theory of Stahl.

The attention of chemical philosophers was soon
n away from the theory of Hooke and Mayow to
f a very different kind, first proposed by Beccher,

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e Sal-nitro et Spiritu Nitro-aereo.

hough Mayow's theory was not original, and though his additions
e absurd, his tract itself displays great genius, and contains a vast
r of new views, which have been fully confirmed by the recent
eries in chemistry. He pointed out the cause of the increase of
t in metals when calcined; he ascertained the changes produced
ir by respiration and combustion;, and employed in his researches
aratus similar to the present pneumatic apparatus of chemists.
s the most curious part of the whole treatise is his fourteenth
r, in which he displays a much more accurate knowledge of *affini-*
han any of his contemporaries, or even successors for many years,

but new modelled by his disciple Stahl with so much skill, arranged in such an elegant systematic form, and furnished with such numerous appropriate and convincing illustrations, that it almost instantly caught the fancy, raised Stahl to the highest rank among philosophers, and constituted him the founder of the Stahlian theory of combustion.

According to Stahl, all combustible substances contain in them a certain body, known by the name of PHLOGISTON, to which they owe their combustibility. This substance is precisely the same in all combustibles. These bodies of course owe their diversity to other ingredients which they contain, and with which the phlogiston is combined. Combustion, and all its attendant phenomena, depend upon the separation and dissipation of this principle; and when it is once separated, the remainder of the body is incombustible. Phlogiston, according to Stahl, is peculiarly disposed to be affected by a violent whirling motion. The heat and the light, which make their appearance during combustion, are merely two properties of phlogiston when in this state of violent agitation.

Improved.

4. The celebrated Macquer, to whose illustrious labours several of the most important branches of chemistry owe their existence, was one of the first persons who perceived a striking defect in this theory of Stahl. Sir Isaac Newton had proved that light is a body; it was absurd, therefore, to make it a mere property of phlogiston or the element of fire. Macquer accordingly considered phlogiston as nothing else but light fixed in bodies. This opinion was embraced by a great number of the most distinguished chemists; and many ingenious arguments were brought forward to prove its

.. But if phlogiston be only light fixed in bodies, ice comes the heat that manifests itself during com- on? Is this heat merely a property of light? Dr : proved that heat is capable of combining with, or ming fixed in bodies which are not combustible, as : or water; and concluded of course, that it is not operty but a body. This obliged philosophers to another view of the nature of phlogiston.

According to them, there exists a peculiar matter, mely subtile, capable of penetrating the densest bo- astonishingly elastic, and the cause of heat, light, ietism, electricity, and even of gravitation. This :r, the *ether* of Hooke and Newton, is also the sub- e called phlogiston, which exists in a fixed state in oustible bodies. When set at liberty, it gives to substances called caloric and light those peculiar ons which produce in us the sensations of heat and . Hence the appearance of caloric and light in y case of combustion; hence, too, the reason that dy after combustion is heavier than it was before; as phlogiston is itself the cause of gravitation, it ld be absurd to suppose that it possesses gravitation; more reasonable to consider it as endowed with a ciple of levity.

Modified by Priestley,

Some time after this last modification of the phlo- c theory, Dr Priestley, who was rapidly extending boundaries of pneumatic chemistry, repeated many :riments formerly made on combustion by Hooke, 'ow, Boyle, and Hales, besides adding many of his .. He soon found, as they had done before him, the air in which combustibles had been suffered to 1 till they were extinguished, had undergone a very arkable change; for no combustible would afterwards burn in it, and no animal could breathe it without suffocation. He concluded that this change was owing to phlogiston; that the air had combined with that substance; and that air is necessary to combustion, by attracting the phlogiston, for which it has a strong affinity. If so, the origin of the heat and light which appear during combustion, remains to be accounted for; since phlogiston, if it separates from the combustible merely by combining with air, cannot surely act upon those bodies in what state soever we may suppose them.

By Crawford,

7. The celebrated Dr Crawford was the first person who attempted to solve this difficulty, by applying to the theory of combustion Dr Black's doctrine of latent heat. According to him, the phlogiston of the combustible combines during combustion with the air, and at the same time separates the caloric and light with which that fluid had been previously united. The heat and the light, then, which appear during combustion, exist previously in the air. This theory was very different from Stahl's, and certainly a great deal more satisfactory. But still the question, What is phlogiston? remained to be answered.

And Kirwan.

8. Mr Kirwan, who had already raised himself to the first rank among chemical philosophers, by many important discoveries, and many ingenious investigations of some of the most difficult parts of chemistry, attempted to answer this question, and to prove that phlogiston is the same with hydrogen. This opinion, which Mr Kirwan informs us was first suggested by the discoveries of Dr Priestley, met with a very favourable reception from the chemical world, and was adopted either in its full extent, or with certain modifications, by Bergman, Morveau, Crell, Wiegleb, Westrum,

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mstadt, Kärsten, Bewley, Priestley, and Delame-
ie. The object of Mr Kirwan was to prove, that
ogen exists as a component part of every combusti-
body; that during combustion it separates from the
bustible body and combines with the oxygen of the
This he attempted in a treatise published on purpose,
led, *An Essay on Phlogiston and the Constitution of
ls* *.

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have omitted, in the historical view given in the text, the hypothe-
blished in 1777 by Mr Scheele, one of the most extraordinary men
ever existed. When very young, he was bound apprentice to an
ecary at Gottenburg, where he first felt the impulse of that genius
h afterwards made him so conspicuous. He durst not indeed devote
lf openly to chemical experiments; but he contrived to make him-
aster of the science by devoting those hours to study which were
ed him for sleep. He afterwards went to Sweden, and settled as
othecary at Köping. Here Bergman first found him, saw his merit
ncouraged it, adopted his opinions, defended him with zeal, and took
himself the charge of publishing his treatises. Encouraged and ex-
by this magnanimous conduct, the genius of Scheele, though unas-
by education or wealth, burst forth with astonishing lustre; and at
when most philosophers are only rising into notice, he had finish-
areer of discoveries which have no parallel in the annals of chemis-
Whoever wishes to behold ingenuity combined with simplicity,
er wishes to see the inexhaustible resources of chemical analysis,
er wishes for a model in chemical researches—has only to peruse
study the works of Scheele.

777, Scheele published a treatise, intitled *Chemical Experiments on
d Fire*, which perhaps exhibits a more striking display of the extent
genius than all his other publications put together. After a vast
r of experiments, conducted with astonishing ingenuity, he con-
, that caloric is composed of a certain quantity of oxygen combined
hlogiston; that radiant heat, a substance which he supposed capa-
being propagated in straight lines like light, and not capable of
ning with air, is composed of oxygen united with a greater quan-
phlogiston, and light of oxygen united with a still greater quanti-
le supposed, too, that the difference between the rays depends upon
antity of phlogiston: the red, according to him, contains the least;

Refuted by Lavoisier.

9. During these different modifications of the Stahlian theory, the illustrious Lavoisier was assiduously occupied in studying the phenomena of combustion. He seems to have attached himself to this subject, and to have seen the defects of the prevailing theory as early as 1770. The first precise notions, however, of what might be the real nature of combustion, were suggested to him by Bayen's paper on the oxides of mercury, which he heard read before the Academy of Sciences in 1774. These first notions, or rather conjectures, he pursued with unwearied industry, assisted by the numerous discoveries which were pouring in from all quarters; and by a long series of the most laborious and accurate experiments and disquisitions ever exhibited in chemistry, he fully established the existence of this general law—" In every case of combustion, oxygen combines with the burning body." This noble discovery, the fruit of genius, industry, and penetration, has reflected new light on every branch of chemistry, has connected and explained a vast number of facts formerly insulated and inexplicable, and has new modelled the whole, and moulded it into the form of a science.

After Mr Lavoisier had convinced himself of the existence of this general law, and had published his proofs to the world, it was some time before he was able to

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the violet the most phlogiston. By *phlogiston* Mr Scheele seems to have meant *hydrogen*. It is needless therefore to examine his theory, as it is now known that the combination of hydrogen and oxygen forms not caloric but water. The whole fabric, therefore, has tumbled to the ground; but the importance of the materials will always be admired, and the ruins of the structure must remain eternal monuments of the genius of the builder.

a single convert, notwithstanding his unwearied as-
ty, and the great weight which his talents, his re-
tion, his fortune, and his situation naturally gave
At last Mr Berthollet, at a meeting of the Aca-
y of Sciences in 1785, solemnly renounced his old
ions, and declared himself a convert Mr Four-
, professor of chemistry in Paris, followed his ex-
le. And in 1787, Morveau, during a visit to Paris,
prevailed upon to relinquish his former opinions,
embrace those of Lavoisier and his friends. The
nple of these celebrated men was soon followed by
ie young chemists of France.

r Lavoisier's explanation of combustion depends
the two laws discovered by himself and Dr Black.
n a combustible body is raised to a certain tempe-
e, it begins to combine with the oxygen of the at-
here, and this oxygen during its combination lets
he caloric and light with which it was combined
e in the gaseous state. Hence their appearance
ng every combustion. Hence also the change which
ombustible undergoes in consequence of combus-

hus Lavoisier explained combustion without having
urse to phlogiston; a principle merely supposed to
, because combustion could not be explained with-
it. No chemist had been able to exhibit phlogis-
n a separate state, or to give any proof for its ex-
ce, excepting only its conveniency in explaining
bustion. The proof for its existence consisted en-
in the impossibility of explaining combustion with-
t. Mr Lavoisier, therefore, by giving a satisfacto-
planation of combustion, without having recourse

to phlogiston, proved, that there was no reason for supposing any such principle at all to exist.

10. But the hypothesis of Mr Kirwan, who made phlogiston the same with hydrogen, was not overturned by this explanation, because there could be no doubt that such a substance as hydrogen actually exists. But hydrogen, if it be phlogiston, must constitute a component part of every combustible, and it must separate from the combustible in every case of combustion. These were points, accordingly, which Mr Kirwan undertook to prove. If he failed, or if the very contrary of his suppositions holds in fact, his hypothesis of course fell to the ground.

Lavoisier and his associates saw at once the important uses which might be made of Mr Kirwan's essay. By refuting an hypothesis which had been embraced by the most respectable chemists in Europe, their cause would receive an eclat which would make it irresistible. Accordingly the essay was translated into French, and each of the sections into which it was divided was accompanied by a refutation. Four of the sections were refuted by Lavoisier, three by Berthollet, three by Fourcroy, two by Morveau, and one by Monge. And, to do the French chemists justice, never was there a refutation more complete. Mr Kirwan himself, with that candour which distinguishes superior minds, gave up his opinion as untenable, and declared himself a convert to the opinion of Lavoisier.

11. Thus Mr Lavoisier destroyed the existence of phlogiston altogether, and established a theory of combustion almost precisely similar to that which had been proposed long ago by Dr Hooke. The theory of Hooke is only expressed in general terms; that of Lavoisier is

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n more particular. The first was a hypothesis or
nate conjecture which the infant state of the science
not enable him to verify; whereas Lavoisier was
to his conclusions by accurate experiments and a
of ingenious and masterly deductions.

Theory of Lavoisier.

ccording to the theory of Lavoisier, which is now
st generally received, and considered by chemists
full explanation of the phenomena, combustion
ists in two things: first, a decomposition; second,
mbination. The oxygen of the atmosphere being
e state of gas, is combined with caloric and light.
ing combustion this gas is *decomposed*, its caloric
light escape, while its base *combines* with the com-
ble and forms the product. This product is in-
bustible; because its base, being already saturated
oxygen, cannot combine with any more. Such is a
t historical detail of the improvements gradually in-
uced into this interesting part of the science of che-
ry. Let us now take a more particular view of the
ect.

. By combustion is meant a total change in the
re of combustible bodies, accompanied by the co-
s emission of heat and light. Every theory of
bustion must account for these two things; name-
e change which the body undergoes, and the emis-
of heat and light which accompanies this change.

Difference between oxygenizement and combustion.

3. Mr Lavoisier explained completely the first of
e phenomena, by demonstrating, that in all cases
en combines with the burning body; and that the
tance which remains behind, after combustion, is
compound formed of the combustible body and
en. But he did not succeed so well in accounting
he heat and the light which are evolved during

combustion. Indeed this part of the subject was in a great measure overlooked by him. The combination of oxygen was considered as the important and essential part of the process. Hence his followers considered the terms *oxygenizement* and *combustion* as synonymous: but this was improper; because oxygen often unites to bodies without any extrication of heat or light. In this way it unites to azote, muriatic acid, and mercury; but the extrication of heat and light is considered as essential to combustion in common language. The union of oxygen without that extrication is very different from its union when accompanied by it, both in the phenomena and in the product; they ought therefore to be distinguished. I employ the term *combustion* in this Work in its usual acceptation.

Difficulty respecting the origin of the heat and light.

14 To account for the emission of heat and light, which constitutes a part of combustion, Mr Lavoisier had recourse to the theory of Dr Crawford. The heat and the light was combined with the oxygen gas, and separated from it, when that gas united to the combustible body. But this explanation, though it answers pretty well in common cases, fails altogether in others. Heat and light were supposed to be combined with the oxygen of the atmosphere, because it is in a gaseous state; and to separate from it, because it loses its gaseous state. But as violent combustions take place when the oxygen employed is solid or liquid, as when it is in the state of a gas. Thus if nitric acid be poured upon linseed oil, or oil of turpentine, a very rapid combustion takes place, and abundance of caloric and light is emitted. Here the oxygen forms a part of the liquid nitric acid, and is already combined with azote; or, according to the language of the French chemists, the

ote has undergone *combustion*. Now, in this case, oxygen is not only in a liquid state, but it has also dergone the change produced by *combustion*. So that ygen is capable of giving out caloric and light, not ly when liquid, but even after combustion ; which is ectly contrary to the theory.

Farther: Gunpowder, when kindled, burns with great idity in close vessels, or under an exhausted recei- . This substance is composed of nitre, charcoal, sulphur : the two last of which ingredients are nbustible ; the first supplies the oxygen, being com- ed of nitric acid and potass. Here the oxygen is only already combined with azote, but forms a com- ent part of a solid ; yet a great quantity of caloric light is emitted during the combustion, and almost whole product of the combustion is in the state of . This appears doubly inconsistent with the theo- for the caloric and light must be supposed to be tted from a solid body during its conversion into which ought to require more caloric and light for xistence in the gaseous state than the solid itself ained.

Removed by Brugnatelli.

5. Mr Brugnatelli, the celebrated professor of che- try at Pavia, seems to have been the first who saw objection in its proper light. He has endeavoured bviate it in the following manner: According to very acute philosopher, the substance commonly ed *oxygen* combines with bodies in two states: 1. aining the greatest part of the caloric and light with ch it is combined when in the state of gas ; 2. Af- aving let go all the caloric and light with which it combined. In the first state, he gives it the name *hermoxygen* ; in the second, of *oxygen*. Thermoxy-

gen exists as a component part, not only of gaseous bodies, but also of several liquids and solids. It is only in those cases where thermoxygen is a component part of liquids or solids that caloric and light are emitted. All metals, according to him, combine with thermoxygen; those substances, on the contrary, which by combustion are converted into acids, combine with oxygen *. This ingenious theory obviates the objection completely, provided its truth can be established in a satisfactory manner. But as the evidence for it rests almost entirely upon its convenience in explaining several difficult points in the phenomena of combustion, we must consider it rather in the light of an ingenious conjecture than as a theory fully established †.

Bodies divisible into supporters, combustibles, and incombustibles.

16. All bodies in nature, as far as combustion is concerned, may be divided into three classes; namely, *supporters*, *combustibles*, and *incombustibles*.

By *supporters*, I mean substances which are not themselves strictly speaking capable of undergoing combustion; but their presence is absolutely necessary, in order that this process may take place. Combustibles and incombustibles require no definition.

Supporters.

Oxygen gas is the only simple supporter known; but when incombustible bodies are united to oxygen, they also become supporters. The only incombustible bodies which possess this property are azote and muriatic acid ‡. It was this singularity which induced me to

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* *Ann. de Chim.* xxix. 182.

† The reader will find this theory very fully detailed in the *Journal de Chimie* of Van Mons, vols 2d and 3d. I avoid entering into particulars, because I can perceive no evidence whatever for the truth of most of the assertions which constitute this theory.

‡ Perhaps mercury might be added to this list. I have failed in all my attempts to cause it to undergo combustion

ate these two substances from all the rest, and them among the simple bodies. The first of these es unites with four doses of oxygen, the second two. Thus we have one simple supporter and ompound; namely,

1. Oxygen gas;
2. Air;
3. Nitrous oxide;
4. Nitric oxide (*nitrous gas*);
5. Nitric acid;
6. Oxymuriatic acid;
7. Hyperoxymuriatic acid.

Combustibles.

7. The combustibles are of three kinds; namely, le, compound, and oxides. The simple are the simple combustibles described in the second Chapf the first Division of this Part; and the whole, or ast almost the whole, of the metals. The comd are the various bodies formed by the union of simple substances with each other; most of which lenominated by terms ending in *uret*, as the sulets, phosphurets, carburets, &c.; and also the al-, and some other compounds which will be descrihereafter. The combustible oxides consist of comtions of the combustible bodies, or their compounds oxygen, without undergoing combustion. They very numerous, constituting the greater part of aniand vegetable substances.

Products.

8. During combustion the oxygen of the supporter ys unites with the combustible, and forms with it w substance, which I shall call a *product* of combus. Hence the reason of the change which combusti-

bles undergo by combustion, as has been sufficiently demonstrated by Lavoisier. Now it deserves attention, that every *product* is always one or other of the three following substances; 1. water, 2. an acid, 3. a metallic oxide.

Partial supporters.

19. Some of the products of combustion are capable of combining with an additional dose of oxygen; but this combination is never attended with the phenomena of combustion, and the product by means of it is converted into a *supporter*. This is the case with several of the metallic oxides. Such compounds may be called *partial supporters*, as it is only to a part of the oxygen which they contain that they owe that property. The following oxides are partial supporters:

1. Peroxide of gold;
2. Peroxide of silver;
3. Red oxide of mercury;
4. Peroxide of mercury;
5. Peroxide of iron;
6. Red and brown oxides of lead;
7. Peroxide of manganese.

These bodies, however, never attract oxygen except from supporters.

20. Since oxygen is capable of supporting combustion only when in the supporters and partial supporters, it cannot be doubted that it is in a different state in these bodies from the state in which it exists in other bodies. Now as light and heat are always emitted during combustion, but never when oxygen combines without combustion, it is natural to suppose that the oxygen of supporters contains either the one or the other of these

s, or both of them ; while the oxygen of other
s wants them altogether.

Oxygen of supporters contains caloric.

m disposed to believe that the oxygen of support-
ontains only caloric, while that body in other cases
nting, or at least not present in sufficient quantity.
eason for this opinion is, that the caloric which is
ed during combustion is always proportional to
uantity of oxygen which combines with the burn-
ody; but this is by no means the case with respect
ht. Thus hydrogen combines with more oxygen
any other body ; and it is now known, that the
produced by the combustion of hydrogen is great-
n can be produced by any other method ; yet the
is barely perceptible.

Combustibles contain light.

. It was long the general opinion of chemists, that
exists in a fixed state in all combustible bodies.
discoveries of Lavoisier induced the greater num-
f them to give up this opinion, on the supposition
combustion could be explained in a satisfactory
er without it. Indeed the followers of that illus-
s philosopher considered it as incumbent upon
to oppose it with all their might ; because the
light, which had been supposed to constitute a
f combustibles, had been unfortunately denominated
iston, a term which they considered as incompa-
with truth. The hypothesis, however, was occa-
lly revived ; first by Richter and Delametherie,
fterwards in a more formal manner by Gren. But
attention has been paid to it in this country till
. The very curious phenomena observed by Mr
evix in his experiments on the hyperoxymuriatic
induced him to incline to the same opinion ; and I
voured to support it in some observations on com-

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bustion, which were published in Nicholson's Journal *.

That the light exists combined with the combustible, will appear exceedingly probable, if we recollect that the quantity which appears during combustion depends altogether upon the combustible. Phosphorus emits a vast quantity, charcoal a smaller, and hydrogen the smallest of all; yet the quantity of oxygen which combines with the combustible during these processes, is greatest in those cases where the light is smallest. Besides, the colour of the light depends in all cases upon the combustible that burns; a circumstance which could scarcely be supposed to take place unless the light were separated from the combustible. It is well known, too, that when vegetables are made to grow in the dark, no combustible substances are formed in them; the presence of light being absolutely necessary for the formation of these substances. These facts, and several others which might be enumerated, give a considerable degree of probability to the opinion that light constitutes a component part of all combustible substances; but they by no means amount to a decisive proof: nor indeed would it be easy to answer all the objections which might be started against this opinion. At the same time, it will be allowed that none of these objections to which I allude amount to a positive proof of the false-

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* Nicholson's *Journal*, 1803, p. 10.—Some very proper remarks were made upon these observations of mine by Mr Portal, and several objections which certainly deserve to be particularly considered. In prosecuting the subject farther, I have obtained some singular enough results, which have indeed removed several objections that had occurred to me as peculiarly formidable; while they have raised in their room a greater number of others which I could not have expected.

ood of the hypothesis. It is always a proof of the dif-
ulty of an investigation, and of the little progress
ich has been made in it, when plausible arguments
n be brought forward on both sides of the question.

Combustion explained.

22. Were we to suppose that the oxygen of support-
s contains caloric as a component part, while com-
stibles contain light, it would not be difficult to ex-
ain what takes place during combustion. The com-
nent parts of the oxygen of supporters are two;
mely, 1. a base; 2. caloric: The component parts of
mbustibles are likewise two; namely, 1. a base; 2.
ht. During combustion the base of the oxygen com-
nes with the base of the combustible, and forms the
oduct; while at the same time the caloric of the ox-
en combines with the light of the combustible, and
e compound flies off in the form of fire. Thus com-
stion is a double decomposition; the oxygen and com-
stible divide themselves each into two portions, which
mbine in pairs; the one compound is the *product*,
d the other the *fire* which escapes.

Hence the reason that the oxygen of products is un-
for combustion. It wants its caloric. Hence the rea-
n that combustion does not take place when oxygen
mbines with products or with the base of supporters.
ese bodies contain no light. The caloric of the oxy-
n of course is not separated, and no fire appears. And
s oxygen still retaining its caloric, is capable of pro-
cing combustion whenever a body is presented which
ntains light, and whose base has an affinity for oxy-
n. Hence also the reason why a combustible alone
n restore combustibility to the base of a product. In
such cases a double decomposition takes place. The
ygen of the product combines with the base of the

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combustible, while the light of the combustible combines with the base of the product.

23. But the application of this theory to the phenomena of combustion is so obvious, that it requires no particular explanation. It enables us to explain, with equal facility, some curious phenomena which occur during the formation of the sulphurets and phosphurets. Sulphur and phosphorus combine with the metals, and with some of the earths. The combination is not formed without the assistance of heat. This melts the sulphur and phosphorus. At the instant of their combination with the metallic or earthy bases, the compound becomes solid, and at the same time suddenly acquires a strong red heat, which continues for some time. In this case the sulphur and phosphorus act the part of a supporter; for they are melted, and therefore contain a great deal of caloric: the metal or earth acts the part of a combustible; for both contain light as a component part. The instant of combination, the sulphur or phosphorus combines with the metal or earth; while the caloric of the one, uniting to the light of the other, flies off in the form of fire. The process therefore may be called *semicombustion*, indicating by the term that it possesses precisely one half of the characteristic marks of combustion.

THIRD SOURCE OF CALORIC.

PERCUSSION.

r is well known that heat is produced by the percus-
on of hard bodies against each other. When a piece
iron is smartly and quickly struck with a hammer,
becomes red hot; and the production of sparks by
e collision of flint and steel is too familiar a fact to re-
iire being mentioned. No heat, however, has ever
en observed to follow the percussion of liquids, nor
soft bodies which easily yield to the stroke.

Percussion produces condensation.

1. This evolution of caloric by percussion seems to
the consequence of a permanent or temporary con-
nsation of the body struck The specific gravity of
on before hammering is 7.788; after being hammer-
l, 7.840: that of platinum before hammering is 19 50;
ter it, 23.00.

Caloric evolved by condensation,

2. Now condensation seems always to evolve caloric;
least this is the case in those bodies in which we can
oduce a remarkable and permanent diminution of bulk.
hen muriatic acid gas is absorbed by water, the li-
iid soon rises to the temperature of 100°; and a still
gher temperature is produced when ammoniacal gas
d muriatic acid gas concrete into a solid salt. When
nestone is dissolved in sulphuric acid, a considerable
eat is produced; notwithstanding the great quantity
carbonic acid which is set at liberty. And if we use
ure lime instead of limestone, a very violent heat takes
ace. Now in this case the acid and the water which
contains are converted partly from liquids to solids,
d the bulk is much diminished. It is known also,

that when air is suddenly condensed, a thermometer surrounded by it rises several degrees *. From the suddenness of the rise in this case, Mr Dalton has shewn that a much greater heat is evolved than is indicated by the thermometer. From his experiments it follows, that when air is suddenly condensed to half its bulk, its temperature is raised 50 degrees †. The same change takes place when air is suddenly admitted into a vacuum. It can scarcely be doubted that a much greater rise of temperature than 50 degrees is occasioned by the condensation of air, provided the fact mentioned by Mollet be precise, that a small bit of linen, rolled up, takes fire when put into the narrow canal in which the lower extremity of a pump for condensing air generally terminates ‡.

On the other hand, when a body is suddenly rarified its temperature is lowered. Mr Dalton has shewn, that by pumping the air out of a receiver, its temperature sinks also 50° §.

And why.

3. It is not difficult to see why condensation should occasion the evolution of caloric, and rarefaction the contrary. When the particles of a body are forced nearer each other the repulsive power of the caloric combined with them is increased, and consequently a

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* Darwin, *Phil. Trans.* 1788.

† *Manchester Memoirs*, v. 515.

‡ Pictet, *Phil. Mag.* xiv. 364.—Connected with this is the appearance of a small light in the air which surrounds the orifice of an air-gun when discharged in the dark. This curious phenomenon, which has not been explained in a satisfactory manner, was first observed by Mr Fletcher (Nicholson's *Journal*, 1803, iv. 280.), and afterwards by Mr Mollet. See *Phil. Mag.* Ibid.

§ *Manchester Memoirs*, v. 515.

rt of it will be apt to fly off. Now, after a bar of
on has been heated by the hammer, it is much harder
d brittler than before. It must then have become
nser, and consequently must have parted with calo-
c. It is an additional confirmation of this, that the
me bar cannot be heated a second time by percussion
ntil it has been exposed for some time to a red heat.
is too brittle, and flies to pieces under the hammer.
ow brittleness seems in most cases owing to the ab-
nce of the usual quantity of caloric. Glass *unanneal-*
, or, which is the same thing, that has been cooled
ry quickly, is always extremely brittle. When glass
in a state of fusion, there is a vast quantity of caloric
cumulated in it, the repulsion between the particles
which must of course be very great; so great indeed,
at they would be disposed to fly off in every direction
ith inconceivable velocity, were they not confined by
unusually great quantity of caloric in the surround-
g bodies: consequently if this surrounding caloric be
moved, the caloric of the glass flies off at once, and
ore caloric will leave the glass than otherwise would
ave it, because the velocity of the particles must be
eatly increased. Probably then the brittleness of glass
owing to the deficiency of caloric; and we can scarce-
doubt that the brittleness of iron is owing to the same
use, if we recollect that it is removed by the applica-
on of new caloric.

Condensation diminishes specific caloric.

4. It deserves attention, too, that condensation dimi-
ishes the specific caloric of bodies. After one of the
ay pieces used in Wedgewood's thermometer has been
eated to 120°, it is reduced to one half of its former
ulk, though it has lost only two grains of its weight,
nd its specific caloric is at the same time diminished

one third*. But we can hardly conceive the specific caloric of a body to be diminished without an evolution of caloric taking place at the same time.

Why heat is occasioned by percussion.

5. These observations are sufficient to explain why caloric is evolved by percussion. It is forced out from the particles of the body struck with which it was formerly combined. But a part of the caloric which is evolved after percussion often originates in another manner. By condensation, as much caloric is evolved as is sufficient to raise the temperature of some of the particles of the body high enough to enable it to combine with the oxygen of the atmosphere. The combination actually takes place, and a great quantity of additional caloric is separated by the decomposition of the gas. That this happens during the collision of flint and steel cannot be doubted; for the sparks produced are merely small pieces of iron heated red hot by uniting with oxygen during their passage through the air, as any one may convince himself by actually examining them. Mr Hawksbee† and others have shewn, that iron produces no sparks in the vacuum of an air-pump; but Mr Kirwan affirms, that they are produced under common spring water.

It is not so easy to account for the emission of caloric on the percussion of two incombustibles. In the last Chapter, mention was made of the light emitted during the percussion of two stones of quartz, flint, felspar, or any other equally hard. Caloric is also emitted during this percussion, as is evident from the whole of the phenomenon. Mr T. Wedgewood found,

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* T. Wedgewood, *Phil. Trans.* 1792.

† Ibid. xxiv. 2165.

at a piece of window-glass, when brought in contact
ith a revolving wheel of grit, became red hot at its
int of contact, and gave off particles which set fire
gunpowder and to hydrogen gas*. We must either
ppose that all the caloric is produced by mere con-
nsation, which is not probable, or acknowledge that
e cannot explain the phenomenon. This is almost the
ly instance of the evolution of caloric and light where
e agency of oxygen cannot be demonstrated or even
ndered probable.

The luminous appearance which follows the percus-
on of certain bodies *in vacuo*, or in bodies which are
t capable of supporting combustion, seems to be con-
cted with electricity; for Mr Davy has observed that
such bodies are electrics. They are frequently also
osphorescent, which property may likewise contri-
ite to the effect†.

FOURTH SOURCE OF CALORIC.

FRICTION.

Emission of caloric by friction,

ALORIC is not only evolved by percussion, but also
friction. Fires are often kindled by rubbing pieces
dry wood smartly against one another. It is well
own that heavy loaded carts sometimes take fire by
e friction between the axle-tree and the wheel. Now
what manner is the caloric evolved or accumulated
friction? Not by increasing the density of the bo-

Not owing to condensation,

Phil. Trans. 1792, p. 45.

† *Jour. of the Royal Instit.* i. 264.

dies rubbed against each other, as happens in cases of percussion; for heat is produced by rubbing soft bodies against each other; the density of which therefore cannot be increased by that means, as any one may convince himself by rubbing his hand smartly against his coat. It is true, indeed, that heat is not produced by the friction of liquids; but then they are too yielding to be subjected to strong friction. It is not owing to the specific caloric of the rubbed bodies decreasing; for Count Rumford found that there was no sensible decrease*, nor, if there were a decrease, would it be sufficient to account for the vast quantity of heat which is sometimes produced by friction.

Nor to decrease of specific caloric,

Count Rumford took a cannon cast solid and rough as it came from the foundery; he caused its extremity to be cut off, and formed, in that part, a solid cylinder attached to the cannon $7\frac{3}{4}$ inches in diameter and $9\frac{8}{10}$ inches long. It remained joined to the rest of the metal by a small cylindrical neck. In this cylinder a hole was bored 3.7 inches in diameter and 7.2 inches in length. Into this hole was put a blunt steel borer, which by means of horses was made to rub against its bottom; at the same time a small hole was made in the cylinder perpendicular to the bore, and ending in the solid part a little beyond the end of the bore. This was for introducing a thermometer to measure the heat of the cylinder. The cylinder was wrapt round with flannel to keep in the heat. The borer pressed against the bottom of the hole with a force equal to about 10,000 lbs. avoirdupois, and the cylinder was turned

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* Nicholson's *Journal*, ii. 106.

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ound at the rate of 32 times in a minute. At the be-
inning of the experiment the temperature of the cy-
nder was 60°; at the end of 30 minutes, when it had
ıade 960 revolutions, its temperature was 130°. The
uantity of metallic dust or scales produced by this fric-
ion amounted to 837 grains. Now, if we were to sup-
ose that all the caloric was evolved from these scales,
s they amounted to just $\frac{1}{948}$ part of the cylinder, they
ıust have given out 948° to raise the cylinder 1°, and
onsequently 66360° to raise it 70° or to 130°, which
certainly incredible*.

Nor to combustion;

Neither is the caloric evolved during friction owing
the combination of oxygen with the bodies them-
elves or any part of them. By means of a piece of
lock-work, Mr Pictet made small cups (fixed on the
xis of one of the wheels), to move round with consi-
erable rapidity, and he made various substances rub
gainst the outsides of these cups, while the bulb of a
ery delicate thermometer placed within them marked
he heat produced. The whole machine was of a size
ufficiently small to be introduced into the receiver of
n air-pump. By means of this machine a piece of a-
amantine spar was made to rub against a steel cup in
ir: sparks were produced in great abundance during
he whole time, but the thermometer did not rise. The
ame experiment was repeated in the exhausted recei-
er of an air-pump (the manometer standing at four
ines); no sparks were produced, but a kind of phos-
horic light was visible in the dark. The thermometer
id not rise. A piece of brass being made to rub in

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* Nicholson's *Journal*, ii. 106.

the same manner against a much smaller brass cup in air, the thermometer (which almost filled the cup) rose 0.3°, but did not begin to rise till the friction was over. This shews us that the motion produced in the air carried off the caloric as it was evolved. In the exhausted receiver it began to rise the moment the friction began, and rose in all 1.2°. When a bit of wood was made to rub against the brass cup in the air, the thermometer rose 0.7°, and on substituting also a wooden cup it rose 2.1°, and in the exhausted receiver 2.4°, and in air condensed to 1¼ atmospheres it rose 0.5°*.

If these experiments be not thought conclusive, I have others to relate, which will not leave a doubt that the heat produced by friction is not connected with the decomposition of oxygen gas. Count Rumford contrived, with his usual ingenuity, to inclose the cylinder above described in a wooden box filled with water, which effectually excluded all air, as the cylinder itself and the borer were surrounded with water, and at the same time did not impede the motion of the instrument. The quantity of water amounted to 18.77 lbs. avoirdupois, and at the beginning of the experiment was at the temperature of 60°. After the cylinder had revolved for an hour at the rate of 32 times in a minute, the temperature of the water was 107°; in 30 minutes more it was 178°; and in two hours and 30 minutes after the experiment began, the water *actually boiled*. According to the computation of Count Rumford, the caloric produced would have been sufficient to heat 26.58 lbs. avoirdupois of ice-cold water boiling hot; and it would

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* Pictet *sur le Feu*, ch. ix.

ve required nine wax candles of a moderate size, burn- ; with a clear flame all the time the experiment last- to have produced as much heat. In this experiment access of water into the hole in the cylinder where friction took place was prevented. But in another periment, the result of which was precisely the same, water was allowed free access *.

And consequently at present inexplicable.

The caloric, then, which appears in consequence of ction, is neither produced by an increase of the den- y, nor by an alteration in the specific caloric of the stances exposed to friction, nor is it owing to the de- nposition of the oxygen of the atmosphere—Whence n is it derived? This question cannot at present be wered: but this is no reason for concluding, with unt Rumford, that there is no such substance as ca- ic at all, but that it is merely a *peculiar kind of mo- n;* because the facts mentioned in the preceding part this Chapter demonstrate the existence of caloric as ubstance. Were it possible to prove that the accu- lation of caloric by friction is *incompatible* with its ng a substance, in that case Count Rumford's conclu- would be a fair one; but this surely has not been e. We are certainly not yet sufficiently acquainted h the laws of the motion of caloric, to be able to af- n with certainty that friction cannot cause it to ac- nulate in the bodies rubbed. This we know at least be the case with electricity. Nobody has been hi- rto able to demonstrate, in what manner it is accu- lated by friction; and yet this has not been thought ufficient reason to deny its existence.

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* Nicholson's *Journal*, ii. 106.

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Analogy between caloric and electricity.

Indeed there seems to be a very close analogy between caloric and electric matter. Both of them tend to diffuse themselves equally, both of them dilate bodies, both of them fuse metals, and both of them kindle combustible substances. Mr Achard has proved, that electricity can be substituted for caloric even in those cases where its agency seems peculiarly necessary; for he found that, by constantly supplying a certain quantity of the electric fluid, eggs could be hatched just as when they are kept at the temperature of 103°. An accident indeed prevented the chickens from actually coming out; but they were formed and living, and within two days of bursting their shell. Electricity has also a great deal of influence on the heating and cooling of bodies. Mr Pictet exhausted a glass globe, the capacity of which was 1200.199 cubic inches, till the manometer within it stood at 1.75 lines. In the middle of this globe was suspended a thermometer, which hung from the top of a glass rod fixed at the bottom of the globe, and going almost to its top. Opposite to the bulb of this thermometer two lighted candles were placed, the rays of which, by means of two concave mirrors, were concentrated on the bulb. The candles and the globe were placed on the same board, which was supported by a non-conductor of electricity. Two feet and a half from the globe there was an electrifying machine, which communicated with a brass ring at the mouth of the globe by means of a metallic conductor. This machine was kept working during the whole time of the experiment; and consequently a quantity of electric matter was constantly passing into the globe, which, in the language of Pictet, formed an atmosphere not only within it, but at some distance round, as was evident

om the imperfect manner in which the candles burned.
hen the experiment began the thermometer stood at
.8°. It rose to 70:2° in 732″. The same experiment
s repeated, but no electric matter thrown in; the ther-
ometer rose from 49.8° to 70.2° in 1050″; so that the
ctricity hastened the heating almost a third. In the
st experiment the thermometer rose only to 71.3°, but
the second it rose to 77°. This difference was doubt-
s owing to the candles burning better in the second
an the first experiment; for in other two experiments
de exactly in the same manner, the maximum was
ual both when there was and was not electric matter
esent. These experiments were repeated with this
ference, that the candles were now insulated, by pla-
g their candlesticks in vessels of varnished glass. The
ermometer rose in the electrical vacuum from 52.2°
74.7° in 1050″; in the simple vacuum in 965″. In
e electrical vacuum the thermometer rose to 77°; in
simple vacuum to 86°. It follows from these ex-
riments, that when the globe and the candles com-
unicated with each other, electricity hastened the heat-
of the thermometer; but that when they were in-
lated separately, it retarded it*. One would be apt
suspect the agency of electricity in the following ex-
riment of Mr Pictet: into one of the brass cups for-
erly described, a small quantity of cotton was put to
event the bulb of the thermometer from being broken.
s the cup turned round, two or three fibres of the
tton rubbed against the bulb, and without any other
iction the thermometer rose five or six degrees. A

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* Pictet *sur le Feu*, chap. vi.

greater quantity of cotton being made to rub against the bulb, the thermometer rose 15°*.

I do not mean to draw any other conclusion from these facts, than that electricity is very often concerned in the heating of bodies, and that probably some such agent is employed in accumulating the heat produced by friction. Supposing that electricity is actually a substance, and taking it for granted that it is different from caloric, does it not in all probability contain caloric as well as all other bodies? Has it not a tendency to accumulate in all bodies by friction, whether conductors or non-conductors? May it not then be accumulated in those bodies which are rubbed against one another? or, if they are good conductors, may it not pass through them during the friction in great quantities? May it not part with some of its caloric to these bodies, either on account of their greater affinity or some other cause? and may not this be the source of the caloric which appears during friction?

FIFTH SOURCE.

MIXTURE.

Mixtures change temperature.

It is well known that in a vast number of cases, when two substances enter into a chemical union, a change of temperature takes place. In some instances the mixture becomes colder than before, while in others it becomes much hotter. In the third Division of the pre-

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* Pictet *sur le Feu*, chap. ix.

ceding Section, a very copious list has been given of the first set of mixtures. It remains for us to consider the nature of the second set, and to endeavour, if possible, to ascertain the cause of the change of temperature.

Water essential.

1. It deserves particular attention, that water constitutes an essential part of almost all mixtures in which a change of temperature takes place. The only exceptions to this rule are some of the gaseous bodies, which when united together constitute a solid body, as ammoniacal and muriatic acid gases. At the instant of union a very considerable heat is evolved. But even these gaseous bodies contain a considerable proportion of water, which in all probability contributes not a little to the effect.

Nature of the change depends on the proportion of water.

2. In many cases the particular change of temperature which is produced by mixture depends upon the proportion of water previously combined with one of the ingredients; for the same ingredients are capable either of producing heat or cold according to that proportion. It has been ascertained by the experiments of Mr Lowitz and Mr Walker, that when salts which contain a great deal of water in their composition, as *carbonat of soda, sulphat of soda, muriat of lime*, &c. are dissolved in water, the temperature sinks considerably; and the fall is proportional to the rapidity of the solution. But when the same salts, previously deprived of their water by exposure to heat, are dissolved, the temperature of the mixture rises considerably.

An increase of density evolves heat,

3. It may be laid down as a rule to which there is no exception, that when the compound formed by the union of two bodies is more fluid or dense than the mean fluidity or density of the two bodies before mixture, then the temperature sinks; but when the fluidity or the den-

And the contrary cold.

sity of the new compound is less than that of the two bodies before mixture, the temperature rises; and the rise is pretty nearly proportional to the difference. Thus when snow and common salt are mixed together, they gradually melt, and assume the form of a liquid. During the whole process of melting the temperature continues at zero or lower; but whenever the solution is completed the temperature rises. On the other hand, when spirits and water are mixed together, a condensation takes place; for the specific gravity is greater than the mean. Accordingly the mixture becomes hot. When four parts of sulphuric acid and one part of water are mixed together, the density is very much increased; accordingly the temperature of the mixture suddenly rises to about 300°.

4. We now see the reason why those salts which contain water in abundance produce cold during their solution: that water, while it constituted a part of them, was in a solid state; but when the salt is dissolved it becomes liquid. Since these salts, if they be deprived of their water, produce heat during their solution, it cannot be doubted that the water, before it dissolves them, combines first with them, so as to form a solid, or at least a solution of considerably greater density.

Solidification of water evolves heat.

5. Whenever water is solidified, a considerable proportion of heat is evolved. Hence the reason that a great deal of heat is produced by sprinkling water upon quicklime. A portion of the water combines with the lime, and forms with it a dry powder totally destitute of fluidity. For the same reason heat is produced when quicklime is thrown into sulphuric acid.

6. The whole of these phenomena, and likewise the

Depends on latent heat.

evolution of heat during putrefaction and fermentation, are sufficiently explained by Dr Black's theory of latent heat. Fluidity, in all cases, is produced by the combination of caloric with the body that becomes fluid. Hence a mixture when it becomes fluid must absorb caloric; which is the same as saying that it must produce cold. On the other hand, when a fluid body becomes solid, heat must be evolved; because a fluid can only become solid by parting with its caloric of fluidity. But the application of the theory to all cases of changes in temperature by mixture is so obvious, that it is quite unnecessary to give any farther illustration.

Such is the present state of our knowledge respecting the sources of caloric, one of the most interesting parts of the science. It is perhaps the most intricate part also. Hence the doubt and uncertainty in which it is still involved, notwithstanding the industry and abilities which have been employed in clearing them up. It deserves attention, that the sources of light and heat are exactly the same; and that these two bodies affect always to accompany one another.

CHAP. III.

OF SIMPLE BODIES IN GENERAL.

WE have now finished the examination of both Divisions of Simple Bodies. Their number amounts to 32. But all the substances, which chemists have not yet succeeded in decompounding, are by no means included in this first Book. Besides the 32 bodies described in the preceding Chapters, there are 12 others[*], whose component parts are still unknown. So that the number of undecompounded bodies amounts to 44. But these 12 resemble so closely other bodies, whose component parts are known, that it would be improper to separate them: a circumstance which renders it exceedingly probable that they also are compounds, and formed of similar ingredients with the other bodies of the classes to which they belong.

Simple bodies concerned in combustion,

I acknowledge, however, that it was not this circumstance alone which induced me to limit the simple substances to the 32 described above. All these 32 are connected together either by common properties, or by the part which they act in *combustion*—by far the most important of all the processes which the chemist consi-

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[*] These are the nine earths, two alkalies, and one acid.

ders as belonging to his science; whereas the remaining undecompounded bodies have no such connection.

The 32 simple substances, in the order in which I have described them, are all concerned in combustion, and contribute to explain it. The knowledge of their properties is necessary to understand that complicated process; and considered in this point of view, they constitute a beautiful whole, which has much more of scientific arrangement than any other part of chemistry is yet capable of assuming. Let us consider them a little in that point of view.

Oxygen is capable of uniting with all the other simple confinable bodies, and it unites with them all in different proportions. With the simple incombustible bodies it unites without the extrication of heat or light; and the new compounds are all *supporters* of combustion. With the simple combustibles it unites, and the union is accompanied by the extrication of heat and light; and the compounds are *products* of combustion. With the metals it unites both with and without the extrication of heat and light, and two classes of compounds are formed; namely, *products* and *supporters*. The simple unconfinable bodies are always extricated during combustion. Thus *combustion* is occasioned by the mutual action of the simple confinable bodies on each other; and the consequence of this action is the extrication of the simple unconfinable bodies.

May be di-
vided into
four classes

It deserves attention, that the metals and simple combustibles approach each other by insensible degrees in their properties. Thus the difference between the properties of arsenic and sulphur is by no means so great as between those of arsenic and gold: they might therefore, without any great impropriety, be reduced under one class. In that case we would have the whole confinable bodies divided into three sets; namely, 1. Supporters; 2. Combustibles; and, 3. Incombustibles. The union of the first and second constitutes products; of the first and third supporters.

Such is the present state of our knowledge of simple substances. But it will be worth while to take a view of the theories of the ancients, the various modifications which they underwent, and the steps by which chemists have been gradually led to the opinions at present received.

Ancients supposed four elements.

It seems to have been an opinion established among philosophers in the remotest ages, that there are only four simple bodies; namely, *fire*, *air*, *water*, and *earth*. To these they gave the name of *elements*, because they believed that all substances are composed of these four. This opinion, variously modified indeed, was maintained by all the ancient philosophers. We now know that all these supposed elements are compounds: *fire* is composed of caloric and light; *air* of oxygen and azotic gases; *water* of oxygen and hydrogen; and *earth*, as will appear afterwards, of nine different substances.

Elements of the alchymists.

The doctrine of the four elements seems to have continued undisputed till the time of the alchymists. These men having made themselves much better acquainted with the analysis of bodies than the ancient philosophers had been, soon perceived that the common doctrine was inadequate to explain all the appearances which were familiar to them. They substituted a theory of their own in its place. According to them, there are three elements, of which all bodies are composed; namely, *salt*, *sulphur*, and *mercury*, which they distinguished by the appellation of the *tria prima*. These principles were

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adopted by succeeding writers, particularly by Paracelsus, who added two more to their number; namely, *phlegm* and *caput mortuum*.

It is not easy to say what the alchymists meant by *salt*, *sulphur*, and *mercury*: probably they had affixed no precise meaning to the words. Every thing which is fixed in the fire they seem to have called *salt*, every inflammable substance they called *sulphur*, and every substance which flies off without burning was *mercury*. Accordingly they tell us, that all bodies may by fire be decomposed into these three principles; the salt remains behind fixed, the sulphur takes fire, and the mercury flies off in the form of smoke. The phlegm and caput mortuum of Paracelsus were the water and earth of the ancient philosophers.

Mr Boyle attacked this hypothesis in his *Sceptical Chemist*, and in several of his other publications; proved that the chemists comprehended under each of the terms salt, sulphur, mercury, phlegm and earth, substances of very different properties; that there is no proof that all bodies are composed of these principles; and that these principles themselves are not elements but compounds. The refutation of Mr Boyle was so complete, that the hypothesis of the *tria prima* seems to have been almost immediately abandoned by all parties.

Altered by Beccher

Meanwhile a very different hypothesis was proposed by Beccher in his *Physica Subterranea*; a hypothesis to which we are indebted for the present state of the science, because he first pointed out chemical analysis as the true method of ascertaining the elements of bodies. According to him, all terrestrial bodies are composed of *water*, *air*, and three *earths*; namely, the *fusible*, the *inflammable* or *sulphureous*, and the *mercurial*.

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The three earths, combined in nearly equal proportions, compose the metals; when the proportion of mercurial earth is very small, they compose stones; when the fusible predominates, the resulting compounds are the precious stones; when the sulphureous predominates, and the fusible is deficient, the compounds are the colorific earths: Fusible earth and water compose a universal acid, very much resembling sulphuric acid, from which all other acids derive their acidity: Water, fusible earth, and mercurial earth, constitute common salt; sulphureous earth, and the universal acid, form sulphur.

And Stahl.

Stahl modified the theory of Beccher considerably. He seems to have admitted the universal acid as an element; the mercurial earth he at last discarded altogether; and to the sulphureous earth he sometimes gave the name of *phlogiston*, sometimes of *ether*. Earths he considered as of different kinds, but containing all a certain element called *earth*. So that, according to him, there are five elements, air, water, phlogiston, earth, the universal acid. He speaks too of heat and light; but it is not clear what his opinion was respecting them.

Gradually banished from the science.

Stahl's theory was gradually modified by succeeding chemists. The universal acid was tacitly discarded, and the different known acids were considered as distinct undecomposed or simple substances: the different earths were distinguished from each other, and all the metallic calces were considered as distinct substances. For these changes chemistry was chiefly indebted to Bergman. While the French and German chemists were occupied with theories about the universal acid, that illustrious philosopher, and his immortal friend and fellow labourer Scheele, loudly proclaimed the neceſſity of considering every undecomposed body as simple till it has been decomposed, and of distinguishing all those substances from each other which possess distinct properties. These cautions, and the consequent arrangement of chemical bodies into distinct classes by Bergman, soon attracted attention, and were at last tacitly acceded to.

Thus the elements of Stahl were in fact banished from the science of chemistry; and in place of them were substituted a great number of bodies which were considered as simple, because they had not been analysed. These were phlogiston, acids, alkalies, earths, metallic calces, water, and oxygen. The rules established by Bergman and Scheele are still followed; but subsequent discoveries have shewn, that most of the bodies which they considered as simple are compounds; while several of their compounds are now placed among simple bodies, because the belief in the existence of phlogiston, which they considered as a component part of these bodies, is now given up.

Present state.

As the term *simple substance* in chemistry means nothing more than a body whose component parts are unknown, it cannot be doubted that, as the science advances towards perfection, many of those bodies which we consider at present as simple will be decomposed; and most probably a new set of simple bodies will come into view of which we are at present ignorant. These may be decomposed in their turn, and new simple bodies discovered; till at last, when the science reaches the highest point of perfection, those really simple and elementary bodies will come into view of which all substances are ultimately composed. When this happens (if it be not above the reach of the human intellect), the

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number of simple substances will probably be much smaller than at present. Indeed, it has been the opinion of many distinguished philosophers in all ages, that there is only one kind of matter; and that the difference which we perceive between bodies depends upon varieties in the figure, size, and density of the primary atoms when grouped together. This opinion was adopted by Newton; and Boscovich has built upon it an exceedingly ingenious and instructive theory. But the full demonstration of this theory is perhaps beyond the utmost stretch of human sagacity.

BOOK II.

OF

COMPOUND BODIES.

COMPOUND BODIES are substances composed of two or more simple bodies combined together. Now as the simple bodies are 32 in number, if they were all capable of combining together, the compounds formed by them would amount to a great many thousands: But all the simple substances are not capable of combining with each other; neither hydrogen, for instance, nor azote, have ever been combined with metals. This diminishes their number considerably. Besides, we are still too little acquainted with the nature of caloric and light to be able to treat separately of the compounds into which they enter. Several numerous classes of compounds have been already described in the last Book: for the oxides, sulphurets, phosphurets, and alloys, are real compounds. All these circumstances render the compounds which form the subject of this Book much less numerous than might be at first supposed.

Division. Compound bodies are of two kinds. Some of them are formed by the combination of two or more *simple*

Book II.

substances with each other. Thus phosphoric acid is composed of phosphorus and oxygen; ammonia, of hydrogen and azote; and oil, of hydrogen and carbon. Others are formed by the combination of two or more *compound* bodies with each other. Thus phosphat of ammonia is composed of phosphoric acid and ammonia; volatile liniment, of oil and ammonia. The first of these kinds of compounds I call PRIMARY COMPOUNDS; to the second I give the name of SECONDARY COMPOUNDS. It will be very convenient to describe each of these separately.

DIVISION I.

OF

PRIMARY COMPOUNDS.

Arrangement.

If the science of chemistry had made sufficient progress, this division would comprehend all the primary compounds which the simple confinable substances are capable of forming. These might all be classed under six heads. Three of these would consist of compounds which oxygen forms with the other simple substances; for all these compounds are either *combustible oxides*, *products*, or *supporters*. The fourth class would consist of the compounds which the simple combustibles form with one another and with the metals; the fifth class, of the combinations of the metals with one another; and the sixth would consist of the combinations of the simple incombustibles with the combustibles and the metals. But in the present imperfect state of the science, the advantages attending this arrangement would not compensate for the violence of the changes which it would introduce. It would oblige us to classify substances together which have always been considered as distinct, and to separate many bodies which have hi-

Book II. Division I.

therto been always grouped together. Besides, we would be forced to omit a number of substances which are still undecompounded, and which are not the less important because they cannot with propriety be introduced among the simple substances. For these reasons I shall arrange the primary compounds under the five following heads :

1. Alkalies.
2. Earths.
3. Oxides.
4. Acids.
5. Compound combustibles.

These shall be the subjects of the five following Chapters.

Chap. I.

CHAP. I.

OF ALKALIES.

THE word ALKALI is of Arabian origin, and was introduced into chemistry after it had been applied to a plant which still retains the name of *kali*. When this plant is burnt, the ashes washed in water, and the water evaporated to dryness, a white substance remains, which was called *alkali*. According to Albertus Magnus, who uses the word, it signifies *fæx amaritudinis*, "the dregs of bitterness *." Alkali may be obtained from other substances besides kali. Chemists gradually discovered that bodies, differing from one another in several of their properties, had been confounded together under the same name. The word, in consequence, became general, and is now applied to all bodies which possess the following properties:

Origin.

Properties.

1. A caustic taste.
2. Volatilized by heat.
3. Capable of combining with acids.
4. Soluble in water even when combined with carbonic acid.
5. Capable of converting vegetable blues to green.

The alkalies at present known are three in number: 1. Potass; 2. Soda; 3. Ammonia.

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* *Theatrum Chemicum*, ii. 470.

The two first are called *fixed alkalies*, because they require a red heat to volatilize them; the last is called *volatile alkali*, because it readily assumes a gaseous form, and consequently is dissipated by a very moderate degree of heat.

SECT. I.

OF POTASS.

Method of procuring potass.

If a sufficient quantity of wood be burnt to ashes, and these ashes be afterwards washed repeatedly with water till it comes off free from any taste, and if this liquid be filtrated and evaporated to dryness, the substance which remains behind is *potass;* not, however, in a state of purity, for it is contaminated with several other substances, but sufficiently pure to exhibit many of its properties. In this state it occurs in commerce under the name of *potash.* When heated to redness, many of its impurities are burnt off: it becomes much whiter than before, and is then known in commerce by the name of *pearl-ash.* Still, however, it is contaminated with many foreign bodies, and is itself combined with carbonic acid gas, which blunts all its properties. It may be obtained perfectly pure by the following process:

1. Mix it with twice its weight of quicklime, and ten times its weight of pure water: Boil the mixture for some hours in a clean iron vessel, or allow it to remain for 48 hours in a close glass vessel, shaking it occasionally. Then pass it through a filter. Boil the liquid

obtained in a silver vessel very rapidly, till it is so much concentrated as to assume when cold the consistence of honey. Then pour upon it a quantity of alcohol equal in weight to one third of the pearl-ash employed. Shake the mixture, put it on the fire, let it boil for a minute or two, then pour it into a glass vessel and cork it up. The solution gradually separates itself into two strata: the lowest consists of the impurities, partly dissolved in water and partly in a solid state; the uppermost consists of the pure potass dissolved in alcohol, and is of a reddish-brown colour. Decant this alcohol solution into a silver bason, and evaporate it rapidly till a black charry crust forms on the surface, and the liquid below acquires such consistence as to become solid on cooling. Then remove the black crust, and pour the solution into a porcelain vessel. When cold, it concretes into a fine white substance, which is pure potass. It muſt be broken to pieces, and put into an air-tight phial.

For this process we are indebted to Berthollet*. The following, which was first proposed by Lowitz of Petersburgh, is less expensive. The potash of commerce and quicklime are to be boiled together as above described. The filtered liquor is then to be evaporated till a thick pellicle appears on its surface, and afterwards allowed to cool; and all the crystals which have formed are to be separated, for they consist of foreign salts. The evaporation is then to be continued in an iron pot; and, during the process, the pellicle which forms on the surface is to be carefully taken off with an iron ſkimmer. When no more pellicle appears, and when the

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* *Jour. de Phys.* xxviii. 401.

matter ceases to boil, it is to be taken off the fire, and must be constantly agitated with an iron spatula while cooling. It is then to be dissolved in double its own weight of cold water. This solution is to be filtered and evaporated in a glass retort * till it begins to deposit regular crystals. If the mass consolidates ever so little by cooling, a small quantity of water is to be added, and it must be heated again. When a sufficient number of crystals have been formed, the liquor which swims over them, and which has assumed a very brown colour, must be decanted off, and kept in a well-closed bottle till the brown matter has subsided, and then it may be evaporated as before, and more crystals obtained †.

The theory of these processes is obvious: The lime separates the carbonic acid, for which it has a stronger affinity; and the alcohol or the evaporation separate all the other foreign ingredients.

Black's discovery of the cause of causticity.

As potass is never obtained at first in a state of purity, but always combined with carbonic acid, it was long before chemists understood to what the changes produced upon it by lime were owing. According to some, it was deprived of a quantity of mucilage, in which it had formerly been enveloped; while, according to others, it was rendered more active by being more comminuted. At last, in 1756, Dr Black proved, by the most ingenious and satisfactory analysis, that the *potass* which the world had considered as a simple substance,

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* Dr Kennedy observes, very justly, that a glass retort ought not to be employed, because potass in this state dissolves glass. *Edin. Trans.* v. 97.

† Nicholson's *Journal*, i. 164.

was really a compound, consisting of potass and carbonic acid; that lime deprived it of this acid; and that it became more active by becoming more simple.

While Dr Black was thus occupied in Scotland. Mr Meyer was employed in Germany in the same researches; from which, however, he drew very different conclusions. His Essays on Lime appeared in 1764. Pouring into lime-water a solution of potass (*carbonat of potass*), he obtained a precipitate, which he ſound not to differ from lime-stone. The alkali had therefore deprived the lime of its causticity and its active properties; and these very properties it had itself acquired. From which he concluded that the causticity of lime was owing to a particular acid with which it had combined during its calcination. The alkali deprived the lime of this acid, and therefore had a stronger affinity for it. To this acid he gave the name of *acidum pingue* or *causticum*. It was, according to him, a subtile elastic mixt, analogous to sulphur, approaching very nearly to the nature of fire, and actually composed of an acid principle and fire. It was expansible, compressible, volatile, astringent, capable of penetrating all vessels, and was the cause of causticity in lime, alkalies, and metals. This theory was exceedingly ingenious, and it was supported by a vast number of new and important facts. But notwithstanding the reputation and acknowledged genius and merit of its author, it never gained many followers; because the true theory of causticity, which had been already published by Dr Black, soon became known on the continent; and notwithstanding some opposition at first, soon carried conviction into every unprejudiced mind. Even Mr Meyer himself readily acknowledged its truth and importance, though he did not at first, on that account, give up his own theory.

That potass was known to the ancient Gauls and Germans cannot be doubted, as they were the inventors of soap, which, Pliny informs us, they composed of ashes and tallow. These ashes (for he mentions the ashes of the beech tree particularly) were nothing else but potass; not, however, in a state of purity [*]. The κονια, too, mentioned by Aristophanes and Plato, appears to have been a ley made of the same kind of ashes. The alchymists were well acquainted with it; and it has been in every period very much employed in chemical researches. It may be said, however, with justice, that till Berthollet published his process in the year 1786, chemists had never examined potass in a state of complete purity [†].

Propertie of potass.

2. Potass is a brittle substance of a white colour, and a smell resembling that which is perceived during the slacking of quicklime. Its taste is remarkably acrid; and it is so exceedingly corrosive, that when applied to any part of the body, it destroys it almost instantaneously. On account of this property, it has been called *caustic*, and is often used by surgeons under the name

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[*] Plinii, lib. xviii. c. 51.

[†] Potass was long distinguished by the name of *vegetable alkali*, because it is obtained from vegetables, and because it was long thought to be peculiar to the vegetable kingdom; but this is now known to be a mistake. It was called also *salt of tartar*, because it may be obtained by burning the salt called *tartar*. Mr Kirwan has given it the name of *tartarin*, Dr Pearson has called it *vegalkali*, Klaproth *kali*, and Dr Black *lixiva*. By most British chemists it is called *potash*; but this term, in common language, signifies the carbonat of potass, or the potass of commerce.

of the *potential cautery*, to open abcesses, and to destroy useless or hurtful excrescences. Its specific gravity is 1.7085 *.

When heated it melts; at a red heat it swells, and evaporates slowly in a white acrid smoke. A strong heat gives it a greenish tinge, but produces no other alteration in it. Potass is not altered by exposure to light.

When exposed to the air, it soon attracts moisture, and is converted into a liquid; at the same time it combines with carbonic acid, for which it has a strong affinity.

Its combination with water;

3. It has a very strong affinity for water. At the common temperature of the air, one part of water dissolves two parts of potass. The solution is transparent, very dense, and almost of the consistence of oil. It is in this state that potass is usually employed by chemists. When four parts of potass in powder and one of snow are mixed together, the mixture becomes liquid, and at the same time absorbs a quantity of caloric. This mixture was employed by Lowitz to produce artificial cold. When the aqueous solution of potass is evaporated to a proper consistency, the potass crystallizes. The shape of its crystals is very different, according to the way in which they have been produced. When allowed to form spontaneously, they are octahedrons in groups, and contain 0.43 of water: When formed by evaporation on the fire, they assume the figure of very thin transparent blades of extraordinary magnitude, which, by an assemblage of lines crossing each other in prodigious

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† Hassenfratz, *Ann. de Chim.* xxviii. 11.

numbers, present an aggregate of cells or cavities, commonly so very close, that the vessel may be inverted without losing one drop of the liquid which it contains *.

Action on oxygen,

4. Potass shews no disposition to unite with oxygen, neither is it altered by the action of any of the compounds into which oxygen enters, though it has a strong tendency to unite with several of these compounds.

On simple combustibles.

5. It unites with none of the simple combustibles except sulphur. Carbon and hydrogen do not act upon it at all; neither does it produce any alteration in them, but it acts upon phosphorus with considerable energy.

Sulphuret of potass.

When three parts of sulphur and one of potass are triturated together in a glass mortar, the sulphur acquires a green colour, the mixture becomes hot, and exhales an aliaceous odour. It gradually attracts moisture from the air, and is totally soluble in water †. When two parts of potass and one of sulphur are heated in a crucible, they melt and combine, and form *sulphuret of potass*. The potash of commerce may be also employed; for the carbonic acid separates in the form of a gas during the combination of the potass and sulphur. When the fusion is complete, the sulphuret is to be poured upon a marble slab; and as soon as it congeals, it must be broken to pieces, and set by into a well-corked phial.

Sulphuret of potass, thus prepared, is of a brown colour, not unlike the liver of animals. Hence it was formerly called *hepar sulphuris*, " liver of sulphur;" but when exposed to the air, it soon becomes green,

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* Nicholson's *Journal*, i. 164.

† Fourcroy, ii. 203.

and even white. It is hard, brittle, and has a glassy fracture. Its taste is acrid, caustic, and bitter, and it leaves a brown stain upon the skin. It has no other smell than that of sublimed sulphur. When exposed to a violent heat the sulphur sublimes, and the potass remains in a state of purity. This sulphuret converts vegetable blues to green, and soon destroys them. When heated with charcoal, it dissolves, and combines with it *.

Hydrogenated sulphuret.

When sulphuret of potass is exposed to the air, or when it is moistened with water, its properties very soon change. It acquires a green colour, and exhales the odour of sulphureted hydrogen gas. This change is owing to the formation of a quantity of sulphureted hydrogen, in consequence of the decomposition of the water. This new-formed substance combines with the sulphuret, and converts it into *hydrogenated sulphuret of potass*, which is soluble in water, and has a brownish green colour. It may be formed also by boiling in water two parts of potass and one part of sulphur. Sulphuret of potass produces no change upon air, but hydrogenated sulphuret gradually absorbs oxygen. When inclosed in a vessel with a quantity of air, it soon absorbs all the oxygen of that portion, and leaves nothing but azotic gas. This fact, which was first observed by Scheele, induced him to use hydrogenated sulphuret to measure the quantity of oxygen contained in any given portion of atmosphoric air. Hydrogenated sulphuret is capable of oxydizing and dissolving almost all the metals. We are indebted to Mr Berthollet for the first ac-

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* Fourcroy, ii. 203.

curate account of the difference between these two substances *.

Action on phosphorus,

Potass cannot be combined with phosphorus by any method at present known. But when potass, dissolved in water, is heated over phosphorus in a retort, the water is gradually decomposed, part of the phosphorus is converted into phosphoric acid, and a great quantity of phosphureted hydrogen gas is emitted, which takes fire as usual as soon as it comes into contact with the air of the atmosphere. It was by this process that Gemgembre first obtained phosphureted hydrogen gas.

Action on simple incombustibles,

6. It does not appear that potass is capable of uniting with azote, or even of acting on it at all : but with muriatic acid it unites very readily, and forms the compound known by the name of muriat of soda.

On metals,

7. Potass does not combine with any of the metals; but some of the metals which have a strong affinity for oxygen, when put into a solution of potass in water, especially if heat be applied, are gradually oxydized. This is the case with molybdenum, zinc, and iron. Tin also is oxydized in a very small proportion; and this seems also to be the case with manganese.

And their oxides.

It is capable of dissolving a considerable number of the metallic oxides ; and in some cases it deprives them of a dose of their oxygen. Thus when poured upon the red oxide of iron it soon converts it into the black. The cause of this change is unknown. It has been ascertained, that the oxides of the following metals are soluble in potass.

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* *Ann. de Chim.* xxv. 233.

Tin,
Nickel,
Zinc,
Antimony,
Tellurium,
Arsenic,
Cobalt,
Manganese,
Tungsten,
Molybdenum.

But the nature of these solutions has not hitherto been examined with any degree of attention; though the subject is remarkably curious, and promises to throw light both upon the nature of alkalies and metals.

Affinities.

The affinities of potass are as follows:

Sulphuric acid,
Nitric,
Muriatic,
Phosphoric,
Fluoric,
Oxalic,
Tartaric,
Arsenic,
Succinic,
Citric,
Lactic,
Benzoic,
Sulphurous,
Acetic,
Saclactic,
Boracic,
Carbonic,
Prussic.

Whether a compound.

Potass has never yet been decomposed. Several chemists, indeed, have conjectured, that it is a compound of lime and azote; and some persons have even endeavoured to prove this by experiment; but none of their proofs are at all satisfactory. We ought, therefore, in

Book II.
Division I.

strict propriety, to have assigned it a place in the First Book: but this would have separated the alkalies from each other, and would have introduced a degree of confusion, which would have more than counterbalanced the logical exactness of the arrangement. Besides, we are certain, from a variety of facts, that all the alkalies are compounds : One of them has actually been decompounded ; and the other two have been detected in the act of formation, though the ingredients which compose them have not hitherto been discovered. Morveau and Desormes indeed announced, some time ago, that they consider potass as a compound of hydrogen and lime. Their chief proofs were the appearance of lime, when the salt, composed of hyperoxygenized muriatic acid and potass, is strongly heated with phosphoric acid in a crucible of platinum ; and a manifest combustion together with the deposition of lime, when charcoal and potass are in like manner exposed to a strong heat in a platinum crucible[†]. But these, and the other experimental proofs, being examined by Darracq, that accurate chemist ascertained that the results obtained by Desormes and Morveau were owing, in most cases, to the impurity of the potass with which they had made their experiments ; while in others, they had drawn wrong inferences from mistaken resemblances[†]. Their hypothesis of course cannot be maintained.

Potass is of the highest importance, not only in chemistry, where it is employed for a great variety of purposes, but also in many arts and manufactures ; as washing, bleaching, dyeing, glass-making, and others, as will afterwards appear. It is employed also in surgery and medicine.

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[*] *Mem. de l'Inst.* iii. 322.

[†] *Ann. de Chim.* xl. 171.

SECT. II.

OF SODA.

Names.

SODA, called also *fossil* or *mineral alkali* *, because it was thought peculiar to the mineral kingdom, was known to the ancients (though not in a state of purity) under the names of νιτρον and *nitrum* †.

Preparation.

It is found in large quantities combined with carbonic acid in different parts of the earth, especially in Egypt; and common salt is a compound of soda and muriatic acid. But the soda of commerce is obtained from the ashes of different species of the *salsola*, a genus of plants which grow upon the sea shore, especially from the *salsola soda*, from which the alkali has obtained its name. The soda of commerce is also called *barilla*, because the plant from which it is obtained bears that name in Spain. Almost all the algæ, especially the fuci, contain also a considerable quantity of soda. The ashes of these plants are known in this country by the name of *kelp*; in France they are called *varec*.

The soda, or barilla of commerce, is far from being pure; besides carbonic acid it contains common salt, and several other foreign ingredients; but it may be obtained perfectly pure by the processes described in the last Section for purifying potass.

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* Dr Pearson has proposed to distinguish it by the name of *fossalkali*; Klaproth calls it *natron*.

† The λιτρον of the Athenians was evidently the same substance; and so was the נתר of the Hebrews.

Soda and potass resemble each other so nearly, that they were confounded together till Du Hamel published his dissertation on common salt in the Memoirs of the French Academy for 1736. He first proved that the base of common salt is soda, and that soda is different from potass. His conclusions were objected to by Pott, but finally confirmed by Margraff in 1758.

Properties.

Soda is of a greyish-white colour, and agrees exactly with potass in its taste, smell, and action upon animal bodies; but its specific gravity is only 1.336*.

Heat produces on it exactly the same effects as upon potass. When exposed to the air, it absorbs moisture and carbonic acid, and is soon reduced to the consistence of paste: but it does not liquefy like potass; in a few days it becomes dry again, and crumbles into powder.

It has a strong affinity for water, dissolves in it like potass, and may also be obtained in crystals by evaporating its aqueous solution. It is not altered by light; nor does it combine with oxygen, hydrogen, azote, carbon, charcoal, nor metals. Its action upon phosphorus and sulphur is the same with that of potass. The sulphuret and hydrogenated sulphuret of soda possess the properties of the sulphuret and hydrogenated sulphuret of potass, and are formed in the same manner. In its action on metals, metallic oxides, and in its affinities, it also agrees with potass. In short, the two fixed alkalies, in a state of purity, resemble each other very nearly in almost every particular.

The component parts of soda are still unknown;

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* Hassenfratz, *Ann. de Chim.* xxviii. 11.

Fourcroy supposed it a compound of magnesia and azote; but this opinion has not been confirmed by experiment. Desormes and Morveau*, on the other hand, affirmed that it is composed of magnesia and hydrogen; but the experiments upon which this opinion was founded have been proved inaccurate by Darracq†. Its importance in manufactures is not inferior to that of potass. For several purposes, indeed, as for the manufacture of soap and glass, it answers even better than potass.

SECT. III.

OF AMMONIA.

AMMONIA may be procured by the following process:

Preparation.

1. Put into a retort a mixture of three parts of quicklime and one part of sal ammoniac in powder. Plunge the beak of the retort below the mouth of a glass jar filled with mercury, and standing inverted in a bason of mercury. Apply the heat of a lamp to the retort: a gas comes over, which displaces the mercury and fills the jar. This gas is *ammonia*.

History.

Ammonia was altogether unknown to the ancients; the alchymists were acquainted with it, though not in a state of purity, being combined with carbonic acid, and often also dissolved in water. Basil Valentine describes the method of obtaining it. It was known by

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* *Mem. de l' Instit.* iii. 321.

† *Ann. de Chim.* xl. 171

the name of *volatile alkali;* it was also called *hatshorn,* because it was often obtained by distilling the horn of the hart; *spirit of urine,* because it may be obtained by the same process from urine; and *spirit of sal ammoniac,* because it may be obtained from that salt. Dr Black first pointed out the difference between ammonia and carbonat of ammonia, or ammonia combined with carbonic acid; and Dr Priestley discovered the method of obtaining it in a state of purity, by the process described in the beginning of this Section.

Properties. 2. Ammonia in the state of gas is transparent and colourless like air; its taste is acrid and caustic like that of the fixed alkalies, but not nearly so strong, nor does it, like them, corrode those animal bodies to which it is applied: its smell is remarkably pungent, though not unpleasant when sufficiently diluted. Its use as a stimulant to prevent fainting is well known.

Animals cannot breathe it without death. When a lighted candle is let down into this gas, it goes out three or four times successively; but at each time the flame is considerably enlarged by the addition of another flame of a pale yellow colour, and at last this flame descends from the top of the vessel to the bottom[*].

Its specific gravity is 0.000732. Its weight is to that of common air as 3 to 5[†].

When exposed to a cold of —45° it is condensed into a liquid, which again assumes the gaseous form when the temperature is raised[‡]. When passed through a red hot tube of porcelain or glass, it is totally decomposed and converted into hydrogen and azotic gas[§].

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[*] Priestley, ii. 381.

[†] Kirwan *on Phlogiston*, p. 28.

[‡] Morveau, *Ann. de Chim.* xxix. 292.

[§] Priestley, ii. 395.

That this experiment may succeed, the diameter of the tube must not be too great.

Combination with water.

3. It combines very rapidly with water. When a bit of ice is brought into contact with this gas, it melts and absorbs the ammonia, while at the same time its temperature is diminished. Cold water absorbs this gas almost instantaneously, and at the same time heat is evolved, and the specific gravity of the water is diminished. Water is capable of absorbing and condensing more than a third of its weight of ammoniacal gas. The specific gravity of the saturated solution is 0.9054 *. It is in this state that ammonia is usually employed by chemists. The term *ammonia* almost always means this liquid solution of ammonia in water. When heated to the temperature of about 130° the ammonia separates under the form of gas. When exposed to the temperature of —46° it crystallizes; and when suddenly cooled down to —68° it assumes the appearance of a thick jelly, and has scarcely any smell†.

It follows from the experiments of Mr Davy, that a saturated solution of ammonia is composed of

74.63	water
25.37	ammonia
100.00	

The following TABLE, drawn up by the same ingenious chemist, exhibits the proportion of water and ammonia contained in 100 parts of liquid ammonia of different specific gravities ‡.

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* Priestley, ii. 381; and Davy, *Researches*, p. 66.

† Fourcroy and Vauquelin, *Ann. de Chim.* xxix. 289.

‡ Davy, p. 68.

Specific gravity.	Ammonia.	Water.
0.9054	25.37	74.63
0.9166	22.07	77.93
0.9255	19.54	80.46
0.9326	17.52	82.48
0.9385	15.88	84.12
0.9435	14.53	85.47
0.9476	13.46	86.54
0.9513	12.40	87.60
0.9545	11.56	88.44
0.9573	10.82	89.18
0.9597	10.17	89.83
0.9619	9.60	90.40
0.9684	9.50	90.50
0.96[illegible]9	9.09	90.91
0.9713	7.17	92.83

Action of electricity.

4. Ammoniacal gas is not altered by light; but when electric sparks are made to pass through it, the bulk of the gas is considerably increased, and it is converted into hydrogen gas and azotic gas *. Hence it follows that it is composed of hydrogen and azote. By this process Berthollet converted 1.7 cubic inches of ammoniacal gas into 3.3 cubic inches †.

Action of oxygen.

5. This gas has no effect upon oxygen gas while cold; but when a mixture of the two gases is made to pass through a red hot porcelain tube, a detonation takes place, water is formed, and azotic gas emitted. Hence we see that ammonia is partly combustible. Its hydrogen combines with the oxygen, and forms water, while the azote makes its escape in the form of a gas ‡. If

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* Priestley, ii. 389.

† Berthollet, *Jour. de Phys.* xxix. 176.

‡ Proust, Nicholson's *Journal*, iii. 328.

the proportion of oxygen gas be considerable, nitric acid is also formed in consequence of the combination of the azote with the superabundant oxygen *. The same decomposition and detonation take place if common air be used instead of oxygen gas.

Action of simple incombustibles.

6. Sulphur is the only one of the simple combustibles that combines with ammonia. Hydrogen produces no change upon it whatever; but phosphorus and charcoal act with considerable effect in high temperatures.

It combines with sulphur in the state of vapour, and forms a sulphuret which decomposes water, and forms *hydrogenated sulphuret of ammonia*, known formerly by the name of *fuming liquor of Boyle*, because it was first described by that philosopher †. It is commonly prepared by distilling a mixture of five parts of sal ammoniac, five parts of sulphur, and six of quicklime. It is a liquid of a red or rather deep orange colour, and exhales a fetid odour in consequence of an excess of ammonia which it contains. Its nature was first pointed out by Berthollet ‡.

Phosphorus produces no change on ammoniacal gas while cold; but when this gas is made to pass through phosphorus in a red hot porcelain tube, it is decomposed, and phosphureted hydrogen gas, and phosphureted azotic gas, are formed §.

Charcoal absorbs ammoniacal gas, but does not alter its properties while cold. But when the gas is made to pass through red hot charcoal, part of the charcoal combines with it, and forms a substance known by the name of *prussic acid* ‖.

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* Fourcroy, ii. 236.

† Shaw's *Boyle*, ii. 78.

‡ *Ann. de Chim.* xxv. 233.

§ Fourcroy, ii. 237

‖ Scheele, ii. 183; and Clouet, *Ann. de Chim.* xi. 30.

Book II. Division I. Of the incombustibles. Of metals.

7. Ammonia is not acted on by azote; but it combines rapidly with muriatic acid; the two gases concreting into the solid salt called *muriat of ammonia*.

8. Ammonia does not combine with the metals; but it changes some of them into oxides, and then dissolves them. The oxidizement is evidently in consequence of the decomposition of part of the water with which the ammonia is combined; for hydrogen gas is emitted during the solution. Copper and zinc are oxidized by the action of ammonia; as are also tin and iron, though only superficially. Scarcely any of the other metals are altered by its action.

Dissolves metallic oxides.

Liquid ammonia is capable of dissolving the oxides of copper, iron, tin, nickel, zinc, bismuth, and cobalt*. When digested upon the oxides of mercury, lead, or manganese, it is decomposed, water is formed by the union of the hydrogen of the ammonia with the oxygen of the oxides, and azotic gas is emitted †. If a considerable heat be applied, nitric acid is formed at the same time with water ‡. Several other oxides are also partly deoxidized when ammonia is poured into their solutions in acids. The ammoniacal solution of the peroxide of copper is of a fine blue colour, and, according to Sage, capable of crystallizing. When heat is applied, the ammonia is partly driven off, and partly decomposed, by the combination of its hydrogen with the oxygen of the oxide.

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* It dissolves the protoxide of iron when added in excess, but only in small quantities. The peroxide of iron is insoluble in it; so is the peroxide of cobalt, according to Thenard.

† Scheele.

‡ Milner, *Phil. Trans.*—Fourcroy, v. 355.

9. Ammonia combines readily with the peroxides of gold and silver, and forms with them two compounds, formerly known by the names of *fulminating gold* and *fulminating silver;* because, when heated or rubbed, they explode with great violence. It combines also with the red oxide of mercury.

Fulminating gold.

Fulminating gold, known also by the name of *aurat of ammonia*, may be prepared by dissolving gold in nitro-muriatic acid, diluting the solution with thrice its weight of water, and then dropping in pure ammonia by little and little as long as any precipitate is formed; taking care not to add too much, because in that case part of the precipitate is again dissolved. The precipitate, which is of a yellow colour, is to be washed in pure water, dried slowly upon filtering paper, and then put into a phial; which, to prevent accidents, ought not to be corked, but its mouth covered with a linen rag or a slip of paper. This powder is fulminating gold; which is composed of five parts of yellow oxide of gold and one part of ammonia*. The preparation of this powder is described by Basil Valentine; and its singular properties excited the attention of all succeeding chemists. Various attempts were made to account for its fulminating property, but without success, till Bergman published his dissertation on it in 1769 He demonstrated, that it is a compound of ammonia and yellow oxide of gold; that during its explosion the oxide is reduced, the ammonia decomposed, and the azote, which it contained, set at liberty in the form of gas †. These facts (partly discovered by Scheele) led

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* Bergman, ii. 155.

† Ibid. 153; and Scheele on Fire, p. 137.

him to explain the explosion as follows: Ammonia is composed of azote and phlogiston. When heat is applied to fulminating gold, the phlogiston combines with the oxide, and forms gold, while the azote flies off in the form of gas. The experiments of Bergman and Scheele were repeated and confirmed by Berthollet in 1786; and the nature of oxides having been previously ascertained by Lavoisier, he was enabled to give a more satisfactory explanation of the phenomenon. During the explosion, the hydrogen of the ammonia combines with the oxygen of the oxide, and forms water; the gold is reduced, and the azote evolved in the form of gas. The great expansibility of this gas by heat explains the violence of the explosion.

Fulminating gold explodes when struck violently, or when triturated in a mortar, or when heated to a temperature between 248° and 540°. The noise is tremendous; and when in any considerable quantity (12 grains for instance) it lacerates the metallic plate on which it is placed. When heated in close vessels, sufficiently strong to resist its action, it is reduced silently, and without any marks of violence*. Its force was compared with that of gunpowder by the Royal Society, but found inferior.

Fulminating silver.

Fulminating silver was discovered by Berthollet in 1788. It may be formed by dissolving very pure silver in nitric acid, and then precipitating it by lime water. The precipitate is put upon filtering paper, which absorbs the water and the nitrat of lime with which it was mixed; then pure liquid ammonia is poured upon

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* Bergman, ii. 141.

it, and allowed to remain for 12 hours; it is then decanted off, and the black powder, on which it stood, is placed cautiously, and in very small portions, upon bits of filtering paper. This powder is fulminating silver. Even while moist it explodes with violence when struck by a hard body. When dry, the slightest touch is sufficient to cause it to fulminate. When the liquid decanted off this powder is heated in a glass retort, an effervescence takes place, azotic gas is emitted, and small crystals make their appearance, which are opaque, and have a metallic brilliancy. These fulminate when touched, even though covered by the liquid, and often break in pieces the vessels in which they are kept *.

The theory of this dangerous powder is the same as that of fulminating gold. It is a compound of ammonia and oxide of silver. Friction, or the application of heat, occasions the combination of the oxygen of the oxide with the hydrogen of the ammonia, water is formed, the silver is reduced, and azotic gas emitted.

Ammoniacal fulminating mercury.

Ammoniacal fulminating mercury was lately discovered by Fourcroy. It may be formed by digesting a strong solution of ammonia in water upon the red oxide of mercury. After the process has continued for eight or ten days, the oxide assumes a white colour, and is at last covered with small crystalline scales. In this state it detonates loudly upon ignited coals in the same manner as fulminating gold. It loses its fulminating property, and undergoes spontaneous decomposition in a few days. When exposed to a low heat, the ammo-

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* Berthollet, *Ann. de Chim.* i. 54.

nia is driven off, and the red oxide assumes its former appearance *.

10. The affinities of ammonia are the same with those of the fixed alkalies.

Composition of ammonia.

11. As ammonia has the property of detonating with nitre, chemists had unanimously agreed that it contains phlogiston. Scheele first demonstrated, that when it is decomposed by means of the oxides of manganese, arsenic, or gold, azotic gas is set at liberty, while the oxide is reduced †. Hence he concluded, that it is composed of azote and phlogiston; and Bergman coincided with him in opinion. Dr Priestley discovered, that when electric explosions are made to pass through this gas, its bulk is gradually augmented to thrice the space which it formerly occupied; and a quantity of hydrogen gas is produced. The same ingenious philosopher applied heat to the red oxides of mercury and lead confined in ammoniacal gas. The oxides were reduced, water was evolved, the ammoniacal gas disappeared, and, instead of it, there was found a quantity of azotic gas ‡. These experiments, and those of Scheele, led to the conclusion, that ammonia is composed of azote and hydrogen; a conclusion which was fully established by the experiments of Berthollet, published in the Memoirs of the French Academy for 1785. This acute philosopher repeated the experiments of Scheele and Priestley, and applied to them the theory of Mr Lavoisier, and added also several very decisive ones of his own. The most important of these is the mutual de-

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* *Journals of the Royal Institution*, i. 256.

† Scheele, i. 95. and 155. French Transl.—Scheele on Fire, p. 137.

‡ Priestley, ii. 396.

composition of ammonia and oxy-muriatic acid. When solutions of these bodies in water are mixed together, an effervescence takes place, azote is disengaged, a quantity of water formed, and the oxy-muriatic acid is converted into common muriatic acid. Now the substances mixed were ammonia and oxy-muriatic acid, which is composed of oxygen and muriatic acid; the products were, muriatic acid, azote, and water, which is composed of oxygen and hydrogen. The oxygen of the water was furnished by the acid; the other products must have been furnished by the ammonia, which has disappeared. Ammonia, therefore, must be composed of azote and hydrogen. It follows from Mr Berthollet's experiments, that ammonia is composed of 121 parts of azote and 29 of hydrogen*. According to Dr Austin, it is composed of 121 parts of azote and 32 of hydrogen †. Hence 100 parts of ammonia are composed of about 80 parts of azote and 20 of hydrogen. The experiments of Berthollet have been still farther confirmed by those made more lately by Mr Davy ‡.

The component parts of ammonia being thus ascertained, nothing was wanting to render the theory complete but the combining of these substances together, and the forming of ammonia by art. Dr Austin mixed hydrogen and azotic gas together in the proper proportions, and endeavoured to make them combine by the application of heat, by electricity, and by cold; but he found, that while these two substances were in a ga-

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* Berthollet determined the component parts of ammonia by decomposing it by electricity, and exploding the new gas with oxygen. *Jour. de Phys.* xxix. 177.

† *Phil. Trans.* 1788.

‡ *Researches*, p. 56.

Book II. Division I.

seous state, they could not be combined by any method which he could devise. It could not be doubted, however, that the combination often takes place when these bodies are presented to each other in a different form. Dr Priestley * and Mr Kirwan † had actually produced it even before its composition was known. Accordingly Dr Austin found, that when tin is moistened with nitric acid, and after being allowed to digest for a minute or two, a little potass or lime is added, ammonia is immediately exhaled. The nitric acid and the water which it contains are decomposed; the oxygen of each unites with the tin, and reduces it to the state of an oxide; and at the same time the hydrogen of the water combines with the azote of the acid, and forms ammonia, which is driven off by the stronger affinity of the potass or lime. Dr Austin succeeded also in forming ammonia by several other methods. He introduced into a glass tube filled with mercury a little azotic gas, and then put into the gas some iron filings moistened with water. The iron decomposes the water and combines with its oxygen; and the hydrogen, meeting with azote at the moment of its admission, combines with it, and forms ammonia. This experiment shews, that the gaseous state of the azote does not prevent its combination with hydrogen.

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* *On Air*, ii. 41.

† *On Hepatic Air*, § iii.

CHAP. II.

OF EARTHS.

THE word EARTH, in common language, has two meanings; it sometimes signifies the *globe* which we inhabit, and sometimes the *mould* on which vegetables grow. Chemists have examined this mould, and have found that it consists of a variety of substances mixed together without order or regularity. The greatest part of it, however, as well as of the stones which form apparently so large a proportion of the globe, consists of a small number of bodies, which have a variety of common properties. These bodies chemists have agreed to class together, and to denominate *earths*.

Every body which possesses the following properties is an *earth*.

Properties.

1. Insoluble in water, or nearly so; or at least becoming insoluble when combined with carbonic acid.

2. Little or no taste or smell; at least when combined with carbonic acid.

3. Fixed, incombustible, and incapable while pure of being altered by the fire.

4. A specific gravity not exceeding 4.9.

5. When pure, capable of assuming the form of a white powder.

6. Not altered when heated with combustibles.

Enumeration.

The earths at present known are nine in number; namely,

1. Barytes.
2. Strontian.
3. Lime.
4. Magnesia.
5. Alumina.
6. Yttria.
7. Glucina.
8. Zirconia.
9. Silica.

Every one of the above characteristics is not perhaps rigorously applicable to each of these bodies; but all of them possess a sufficient number of common properties to render it useful to arrange them under one class.

SECT. I.

OF BARYTES.

History.

Barytes was discovered by Scheele in 1774; and the first account of its properties published by him in his Dissertation on Manganese* There is a very heavy mineral, most frequently of a flesh colour, of a foliated texture and brittle, very common in Britain and most other countries, especially in copper mines. It was known by the name of *ponderous spar*, and was supposed to be a compound of sulphuric acid and lime. Gahn analysed this mineral in 1775, and discovered that it is composed of sulphuric acid and the new earth dis-

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[*] Scheele, i. 61. and 78. French Translation.

covered by Scheele[*]. The experiments of these chemists were confirmed by Bergman[†], who gave the earth the name of *terra ponderosa*. Morveau gave it the name of *barote*, and Kirwan of *barytes*[‡]; which last was approved of by Bergman[§], and is now universally adopted. Different processes for obtaining barytes were published by Scheele, Bergman, Wiegleb, and Afswelius; but little addition was made to the properties ascertained by the original discoverer till Dr Hope published his experiments in 1793[‖]. In 1797, our knowledge of its nature was still farther extended by the experiments of Pelletier, Fourcroy, and Vauquelin[¶].

Preparation.

1. Barytes may be obtained from ponderous spar, or *sulphat of barytes*, as it is now called, by the following process, for which we are indebted to Vauquelin. Reduce the mineral to a fine powder; mix it with the eighth part of its weight of charcoal powder, and keep it for some hours red hot in a crucible, and it will be converted into sulphuret of barytes. Dissolve the sulphuret in water, and pour nitric acid into the solution, and the sulphur will be precipitated. The solution, which consists of nitric acid combined with barytes, is to be filtered and evaporated slowly till it crystallizes. Put the crystals into a crucible, and expose it to a strong heat, the nitric acid is driven off, and the barytes remains in a state of purity[**].

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[*] Bergman's Notes on Scheffer, § 167.

[†] *Opusc.* iii. 291.

[‡] From Βαρυς, heavy.

[§] *Opusc*, iv. 261.

[‖] *Edin. Trans.* iv. 36.

[¶] *Ann. de Chim.* xxi. 113. and 276.

[**] When thus prepared, it always contains about 0.08 of carbonat of barytes, and sometimes much more.

Another method, attended with less expence, was pointed out long ago by Dr Hope, and has been since proposed by several foreign chemists, without taking any notice of the original discoverer. The method is this: Decompose the sulphat of barytes by heating it strongly along with charcoal powder. The product is to be treated with water to dissolve every thing that is soluble; and the liquid, being filtered, is to be mixed with a solution of carbonat of soda. A white powder falls. Wash this powder; make it up into balls with charcoal, and heat it strongly in a crucible. When these balls are treated with boiling water, a portion of barytes is dissolved, which crystallizes as the water cools.

Properties.

2. Barytes obtained by the first method is a greyish-white, porous body, which may be very easily reduced to powder. It has a harsh and more caustic taste than lime; and when taken into the stomach, proves a most violent poison. It has no perceptible smell. It tinges vegetable blues green, and decomposes animal bodies like the fixed alkalies, though not with such energy.

Its specific gravity, according to Fourcroy *, is 4; but according to Hassenfratz, only 2.374 †. But there is reason to conclude, from the method employed by this philosopher, that the specific gravities which he assigns are all too low.

When heated it becomes harder, and acquires internally a bluish-green shade. When exposed to the blow-pipe on a piece of charcoal, it fuses, bubbles up, and runs into globules, which quickly penetrate the char-

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* Fourcroy, ii. 189.

† *Ann. de Chim.* xxviii. 11.

coal *. This is probably in consequence of containing water, for Lavoisier found barytes not affected by the strongest heat which he could produce.

When exposed to the air, it immediately attracts moisture; in consequence of which it swells, heat is evolved, and the barytes falls to a white powder, just as happens to quicklime when water is sprinkled on it †. After the barytes is thus *slacked*, it gradually attracts carbonic acid, and loses its acrid properties, its weight being encreased 0.22 ‡. It cannot therefore be kept pure except in close vessels.

Action of water.

3. When a little water is poured upon barytes it is slacked like quick lime, but more rapidly, and with the evolution of more heat. The mass becomes white, and swells considerably. If the quantity of water be sufficient to dilute it completely, the barytes crystallizes in cooling, and assumes the appearance of a stone composed of needle-form crystals; but when exposed to the air it gradually attracts carbonic acid and falls to powder ||.

Water is capable of dissolving 0.05 parts of its weight of barytes. This solution, which is known by the name of *barytes water*, is limpid and colourless, has an acrid taste, and converts vegetable blues first to a green and then destroys them. When exposed to the air, its surface is soon covered with a stony crust, consisting of the barytes combined with carbonic acid.

Boiling water dissolves more than half its weight of barytes. As the solution cools, the barytes is deposited

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* Fourcroy and Vauquelin, *Ann de Chim.* xxi. 276.

† Id ibid. 2 59.

‡ *Mem. de l'Institut.* ii. 59.

|| Fourcroy, ii. 193.

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in crystals; the shape of which varies according to the rapidity with which they have been formed. When most regular, they are flat hexagonal prisms, having two broad sides, with two intervening narrow ones, and terminated at each end by a four-sided pyramid, which in some instances constitutes the larger part of the crystal. When formed slowly they are distinct and large; but when the water is saturated with barytes, they are deposited rapidly, and are generally more slender and delicate. Then, too, they are attached to one another in such a manner as to assume a beautiful foliaceous appearance, not unlike the leaf of a fern *.

These crystals are transparent and colourless, and appear to be composed of about 53 parts of water and 47 of barytes. When exposed to the heat of boiling water, they undergo the *watery fusion;* that is to say, the water which they contain becomes sufficient to keep the barytes in solution. A stronger heat makes the water fly off. When exposed to the air, they attract carbonic acid, and crumble into dust. They are soluble in $17\frac{1}{2}$ parts of water at the temperature of 60°; but boiling water dissolves any quantity whatever: the reason of which is evident; at that temperature their own water of crystallization is sufficient to keep them in solution †.

Action of oxygen.

4. Barytes undergoes no change from light; neither is it capable, as far as is known, of combining with oxygen.

Of the simple combustibles.

5. None of the simple combustibles combine with it except sulphur and phosphorus.

Sulphuret of barytes may be formed by mixing its two ingredients together and heating them in a crucible.

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* Hope, *Edin. Trans.* iv. 36.

† Ibid.

The mixture melts at a red heat, and when cold forms a mass of a reddish-yellow colour, without any smell, which is *sulphuret of barytes*. This sulphuret decomposes water with great rapidity, sulphureted hydrogen is formed, which, combining with the sulphuret, converts it into a hydrogenated sulphuret. This change takes place whenever the sulphuret is moistened with water, or even exposed to the atmosphere. When boiling water is poured upon sulphuret of barytes, a great quantity of sulphureted hydrogen is formed almost instantaneously, which combines with the water and occasions the solution of the sulphuret. When the solution cools, a great number of brilliant white crystals are deposited, sometimes in the form of needles, sometimes in six-sided prisms, and sometimes in hexagonal plates. These crystals are composed of sulphureted hydrogen and barytes, and have been called by Berthollet, to whom we are indebted for the first accurate account of them, *hydrosulphuret of barytes*. The liquid which has deposited the hydrosulphuret is of a yellow colour, and holds in solution a *hydrogenated sulphuret of barytes* *.

Phosphuret.

Phosphuret of barytes may be formed by putting a mixture of phosphorus and barytes into a glass tube close at one end, and heating the mixture by putting the tube upon burning coals. The combination takes place very rapidly. This phosphuret is of a dark brown colour, very brilliant and very fusible. When moistened, it exhales the odour of phosphureted hydrogen gas. When thrown into water, it is gradually decomposed, phosphureted hydrogen gas is emitted, which takes fire

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* Berthollet, *Ann. de Chim.* xxv. 233.

when it comes to the surface of the water, and the phosphorus is gradually converted into phosphoric acid *.

Action of incombustibles.

6. Barytes is not acted on by azote: but it combines readily with muriatic acid, and forms a compound called *muriat of barytes*.

Action of metals and their oxides,

7. Barytes has no action on metals; but it is capable of combining with several of the metallic oxides, and forming with them compounds which have not hitherto been much examined. For instance, if it be poured into a solution of silver or lead in nitric acid, it precipitates the first brown, and the second white; but if an excess of barytes water be added, the precipitates are redissolved †.

Of alkalies.

8. Barytes does not combine with the alkalies. Its component parts are unknown; but it resembles the alkalies in so many of its properties, that one cannot help thinking that the composition of both is analogous.

Affinities.

9. Its affinities, according to Bergman, observe the following order:

Sulphuric acid,
Oxalic,
Succinic,
Fluoric,
Phosporic,
Saclactic,
Nitric,
Muriatic,

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* Fourcroy, ii. 191.

† Fourcroy and Vauquelin, *Mem. de l'Instit.* ii. 61.

Chap. II.

Suberic,
Citric,
Tartaric,
Arsenic,
Lactic,
Benzoic,
Acetic,
Boracic,
Sulphurous,
Carbonic,
Prussic.

SECT. II.

OF STRONTIAN.

History.

ABOUT the year 1787 a mineral was brought to Edinburgh, by a dealer in fossils, from the lead mine of Strontian, in Argyleshire, where it is found imbedded in the ore, mixed with several other substances. It is sometimes transparent and colourless, but generally has a tinge of yellow or green. Its hardness is 5. Its specific gravity varies from 3.4 to 3.726. Its texture is generally fibrous; and sometimes it is found crystallized in slender prismatic columns of various lengths[*].

This mineral was generally considered as a carbonat of barytes; but Dr Crawford having observed some differences between its solution in muriatic acid and that

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[*] Hope, *Edin. Trans.* iv. 44.

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of barytes, mentioned, in his treatise on *muriat of barytes* published in 1790, that it probably contained a new earth, and sent a specimen to Mr Kirwan that he might examine its properties. Dr Hope made a set of experiments on it in 1791, which were read to the Royal Society of Edinburgh in 1792, and published in the Transactions about the beginning of 1794. These experiments demonstrate, that the mineral is a compound of carbonic acid, and a peculiar earth, whose properties are described. To this earth Dr Hope gave the name of *strontites*. Klaproth analysed it also in 1793, and drew the same conclusions as Dr Hope, though he was ignorant of the experiments of the latter, which remained still unpublished. Klaproth's experiments were published in Crell's *Annals* for 1793 * and 1794 †. Kirwan also discovered the most interesting peculiarities of this new earth in 1793, as appears by his letter to Crell, though his dissertation on it, which was read to the Irish Academy in 1794, was not published till 1795. The experiments of these philosophers were repeated and confirmed in 1797 by Pelletier, Fourcroy, and Vauquelin §, and several of the properties of the earth still farther investigated. To the earth thus detected Klaproth gave the name of *Strontian*, from the place where it was first found; and this name is now generally adopted.

Strontian is found abundantly in different places of the world, and always combined with carbonic acid or sulphuric acid.

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* Vol. ii. 189.

† Vol. i. 99 See also Klaproth's *Beitrage*, i. 260. and *Jour. de Min.* No. v. p. 61.

§ *Ann. de Chim.* xxi. 113. and 276. *Jour. de Min.* An. vi. 3.

Preparation.

1. The carbonic acid may be expelled from the carbonat, and the strontian obtained pure by mixing the mineral with charcoal powder, and exposing it to a heat of 140° Wedgewood[*]; or by dissolving the mineral in nitric acid, evaporating the solution till it crystallizes, and exposing the crystals in a crucible to a red heat till the nitric acid is driven off. Strontian may be obtained from the sulphat by following exactly the process described in the last Section for obtaining barytes.

Properties.

2. Strontian, thus obtained, is in porous masses, of a greyish white colour; its taste is acrid and alkaline; and it converts vegetable blues to green. Its specific gravity, according to Hassenfratz, is 1.647[†]. It does not act so strongly on animal bodies as barytes, nor is it poisonous[‡].

It does not melt when heated like barytes; but before the blow-pipe it is penetrated with light, and surrounded with a flame so white and brilliant that the eye can scarcely behold it[§].

Action of water,

3. When water is sprinkled on strontian it is slacked, becomes hot, and falls to powder exactly like barytes; but it is not so soluble in water as that earth. One hundred and sixty-two parts of water, at the temperature of 60°, dissolve nearly one part of strontian. The solution, known by the name of *strontian water*, is clear and transparent, and converts vegetable blues to a green. Hot water dissolves it in much larger quantities; and as it cools the strontian is deposited in colourless transparent crystals. These are in the form of thin qua-

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[*] Kirwan.

[†] *Ann. de Chim.* xxviii. 11.

[‡] Pelletier, Ibid. xxi. 120.

[§] Fourcroy, ii. 227.

drangular plates, generally parallelograms, the largest of which seldom exceeds one-fourth of an inch in length. Sometimes their edges are plain, but they oftener consist of two facets, meeting together, and forming an angle like the roof of a house. These crystals generally adhere to each other in such a manner as to form a thin plate of an inch or more in length and half an inch in breadth. Sometimes they assume a cubic form. They contain about 68 parts in 100 of water. They are soluble in 51.4 parts of water, at the temperature of 60°. Boiling water dissolves nearly half its weight of them. When exposed to the air, they lose their water, attract carbonic acid, and fall into powder*. Their specific gravity is 1.46†.

Of oxygen,

4. Strontian is not acted on by light; neither does it combine with oxygen.

Of combustibles.

5. Sulphur and phosphorus are the only simple combustibles with which it unites.

Sulphuret.

The sulphuret of strontian may be made by fusing the two ingredients in a crucible. It is soluble in water by means of sulphureted hydrogen, which is evolved. When the solution is evaporated, *hydrosulphuret of strontian* is obtained in crystals, and *hydrogenated sulphuret* remains in solution. These three compounds resemble almost exactly the sulphuret, hydrosulphuret, and hydrogenated sulphuret of barytes; and do not therefore require a particular description. The same remark applies to the phosphuret of strontian, which may be prepared by the same process as the phosphuret of barytes‡.

Phosphuret.

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* Hope, *Edin. Trans.* iv. 44. † Hassenfratz, *Ann. de Chim.* xxviii. 11.

‡ Vauquelin, *Jour. de Min.* An. vi. 17.

Action of incombustibles, metals, and alkalies.

6. Strontian does not combine with azote; but it unites readily with muriatic acid, and forms the substance called muriat of strontian.

7. Strontian has no action upon metals; but it combines with several of their oxides, and forms compounds which have not hitherto been examined.

8. It does not combine with alkalies nor with barytes. No precipitation takes place when barytes and strontian water are mixed together[*].

Tinges flame red.

9. Strontian has the property of tinging flame of a beautiful red, or rather purple colour; a property discovered by Dr Ash in 1787. The experiment may be made by putting a little of the salt composed of nitric acid and strontian into the wick of a lighted candle[†]; or by setting fire to alcohol, holding muriat of strontian in solution. In both cases the flame is of a lively purple. In this respect it differs from barytes, which when tried in the same way is found to communicate a bluish yellow tinge to flame[‡].

Affinities.

10. The affinities of strontian, as ascertained by Dr Hope and Mr Vauquelin, are as follows:

Sulphuric acid,
Phosphoric,
Oxalic,
Tartaric,
Fluoric,
Nitric,
Muriatic,
Succinic,

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[*] Morveau, *Ann. de Chim.* xxxi. 251.

[†] Vauquelin, *Jour. de Min.* An. vi. 10.

[‡] Pelletier, *Ann. de Chim.* xxi. 137.

Acetic,
Arsenic,
Boracic,
Carbonic.

Barytes and strontian resemble each other in their properties as closely as potass and soda: hence, like these two alkalies, they were for some time confounded. It is in their combination with acids that the most striking differences between these two earths are to be observed.

SECT. III.

OF LIME.

LIME has been known from the earliest ages. The ancients employed it in medicine; it was the chief ingredient in their mortar; and they used it as a manure to fertilize their fields.

Lime abounds in most parts of the world, or perhaps I should rather say, that there is no part of the world where it does not exist. It is found purest in limestones, and marbles, and chalk. None of these substances, however, is, strictly speaking, lime; but they are all capable of becoming lime by a well-known process, by keeping them for some time in a white heat: this process is called *the burning of lime*. The product, which in common language is denominated *quicklime*, is the substance known in chemistry by the name of *lime*.

Preparation.

1. Lime may be obtained perfectly pure by burning those crystallized limestones called *calcareous spars*, which are perfectly white and transparent, and also by burning some pure white marbles. It may be procured also in a state of purity by dissolving oyster shells in muriatic acid, filtering the solution, mixing it with ammonia as long as a white powder continues to fall, and filtering again. The liquid is now to be mixed with a solution of carbonat of soda: the powder which falls being washed and dried, and heated violently in a platinum crucible, is pure lime.

Properties.

2. Pure lime is of a white colour, moderately hard, but easily reduced to a powder.

It has a hot burning taste, and in some measure corrodes and destroys the texture of those animal bodies to which it is applied. Its specific gravity is 2.3 *. It tinges vegetable blues green, and at last converts them to yellow.

It is incapable of being fused by the most violent heat that can be produced in furnaces, or even by the most powerful burning glasses.

Slacking of lime.

3. If water be poured on newly burnt lime, it swells and falls to pieces, and is soon reduced to a very fine powder. In the mean time, so much heat is produced, that part of the water flies off in vapour. If the quantity of lime slacked (as this process is termed) be great, the heat produced is sufficient to set fire to combustibles. In this manner, vessels loaded with lime have sometimes been burnt. When great quantities of lime are slacked in a dark place, not only heat but light al-

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* Kirwan's *Miner.* i. 5.

so is emitted, as Mr Pelletier has observed *. When slacked lime is weighed, it is found to be heavier than it was before. This additional weight is owing to the combination of part of the water with the lime; which water may be separated again by the application of a red heat; and by this process the lime becomes just what it was before being slacked †. Hence the reason of the heat evolved during the slacking of lime. Part of the water combines with the lime, and thus becomes solid; of course it parts with its caloric of fluidity, and probably also with a considerable quantity of caloric, which exists in water even when in the state of ice: for when two parts of lime and one part of ice (each at 32°) are mixed, they combine rapidly, and their temperature is elevated to 212°. The elevation of temperature during the slacking of barytes and strontian is owing to the same cause.

The smell perceived during the slacking of lime is owing to a part of that earth being elevated along with the vapour of the water; as evidently appears from this circumstance, that vegetable blues exposed to this vapour are converted to green.

Difference between limestone and lime

Limestone and chalk, though they are capable of being converted into lime by *burning*, possess hardly any of the properties of that active substance. They are tasteless, scarcely soluble in water, and do not perceptibly act on animal bodies. Now, to what are the new properties of lime owing? What alteration does it undergo in the fire?

It had been long known, that limestone loses a good

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* *Jour. de Phys.* t. 22.

† Dr Black.

deal of weight by being burned or *calcined*. It was natural to suppose, therefore, that something is separated from it during calcination. Accordingly, Van Helmont, Ludovicus, and Macquer, made experiments in succession, in order to discover what that *something* is ; and they concluded from them that it is *pure water*, which the lime recovers again when exposed to the atmosphere. As the new properties of lime could hardly be ascribed to this loss, but to some other cause, Stahl's opinion, like all the other chemical theories of that wonderful man, was generally acceded to. He supposed that the new properties which lime acquired by calcination are owing entirely to the more minute division of its particles by the action of the fire. Boyle indeed had endeavoured to prove, that these properties are owing to the *fixation of fire* in the lime : a theory which was embraced by Newton and illustrated by Hales, and which Meyer new modelled, and explained with so much ingenuity and acuteness as to draw the attention of the most distinguished chemists. But while Meyer was thus employed in Germany, Dr Black of Edinburgh published in 1756 those celebrated experiments which form so brilliant an era in the history of chemistry.

Discovered by Dr Black.

He first ascertained, that the quantity of water separated from limestone during its calcination is not nearly equal to the weight which it lost. He concluded in consequence, that it must have lost something else than mere water. What this could be, he was at first at a loss to conceive ; but recollecting that Dr Hales had proved, that limestone, during its solution in acids, emits a great quantity of *air*, he conjectured that *this* might probably be what it lost during calcination. He calcined it accordingly, and applied a pneumatic apparatus to receive the product. He found his conjecture verified; and that the *air* and the *water* which separated from the lime were together precisely equal to the loss of weight which it had sustained. Lime therefore owes its new properties to the loss of *air;* and limestone differs from lime merely in being combined with a certain quantity of *air:* for he found that, by restoring again the same quantity of *air* to lime, it was converted into limestone. This air, because it existed in lime in a fixed state, he called *fixed air*. It was afterwards examined by Dr Priestley and other philosophers; found to possess peculiar properties, and to be that species of gas now known by the name of *carbonic acid gas*. Lime then is a simple substance, and limestone is composed of carbonic acid and lime. Heat separates the carbonic acid, and leaves the lime in a state of purity.

5. When lime is exposed to the open air, it gradually attracts moisture, and falls to powder; after which it soon becomes saturated with carbonic acid, and is again converted into carbonat of lime or unburnt limestone.

Action of water,

Water, at the common temperature of the atmosphere, dissolves about 0.002 parts of its weight of lime. This solution is called *lime-water*. It is limpid, has an acrid taste, and changes vegetable blue colours to green. One ounce troy of lime-water contains about one grain of lime. It is usually formed by throwing a quantity of lime in powder into pure water, allowing it to remain for some time in a close vessel, and then decanting the transparent solution from the undissolved lime. When lime-water is exposed to the air, a stony crust soon forms on its surface composed of carbonat of lime;

when this crust is broken it falls to the bottom and another succeeds it; and in this manner the whole of the lime is soon precipitated, by absorbing carbonic acid from the air.

If we believe Trommsdorf, lime may be obtained in the state of crystals. The process by which he procured it in that state is the following: Take four parts of liquid muriat of lime* and one part of lime; mix them together; and boil the liquid till a drop, on cooling, assume the consistence of syrup: then filter it thro' a cloth into an earthen vessel, which must be covered with a lid. When this liquid is allowed to cool slowly, long needle-shaped crystals of pure lime shoot in it. The experiment does not succeed unless performed in a pretty large scale. Some pounds of muriat of lime at least must be used †.

6. Lime is not acted on by light, neither does it combine with oxygen.

Of combustibles.

7. Sulphur and phosphorus are the only simple combustibles with which it unites.

Sulphuret.

Sulphuret of lime may be formed by mixing its two component parts, reduced to a powder, and heating them in a crucible. They undergo a commencement of fusion, and form an acrid reddish mass When it is exposed to the air, or moistened with water, its colour becoming greenish-yellow, sulphureted hydrogen is formed, and the sulphuret is converted into a hydrogenated sulphuret, which exhales a very fetid odour of sulphureted hydrogen gas. This hydrogenated sulphu-

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* A salt composed of muriatic acid and lime, to be described hereafter.

† *Phil. Mag.* xii. 83.

ret may be formed also by boiling a mixture of lime and sulphur in about ten times its weight of water, or by sprinkling quicklime with sulphur and then moistening it: the heat occasioned by the slacking of the lime is sufficient to form the combination. When this hydrogenated sulphuret is exposed to the air, it imbibes oxygen, which combines at first with the hydrogen, and afterwards with the sulphur, and converts the compound into sulphat of lime *. When the solution of hydrogenated sulphuret of lime is kept in a close vessel, the sulphur gradually precipitates, and hydrosulphuret of lime remains in solution.

The hydrogenated sulphuret of lime has the property of dissolving charcoal by the assistance of heat, and of retaining it in solution †. It acts very powerfully upon metals and metallic oxides.

Phosphuret.

Phosphuret of lime may be formed by the following process: Put into the bottom of a glass tube, close at one end, one part of phosphorus; and, holding the tube horizontally, introduce five parts of lime in small lumps, so that they shall be about two inches above the phosphorus. Then place the tube horizontally among burning coals, so that the part of it which contains the lime may be made red hot, while the bottom of the tube containing the phosphorus remains cold. When the lime becomes red hot, raise the tube, and draw it along the coals till that part of it which contains the phosphorus is exposed to a red heat. The phosphorus is immediately volatilized, and passing through the hot lime combines with it. During the combination the mass

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* Berthollet.

† Fourcroy, ii. 174.

becomes of a glowing red heat, and a quantity of phosphureted hydrogen gas is emitted, which takes fire when it comes into the air. This curious process was contrived by Dr Pearson, to whom we are indebted for the discovery of the earthy phosphurets *.

Phosphuret of lime has a deep brown colour, and is moulded into the shape of the tube. It has no smell, and falls to pieces in the air. It is insoluble in water; but it has the property of decomposing that liquid. Phosphureted hydrogen gas is emitted, which takes fire as soon as it comes to the surface of the water. Part of this gas combines with the phosphuret, and forms a kind of hydrogenated phosphuret. Hence it happens that if phosphuret of lime, after being kept for some time in water, be taken out and dried, it flames when muriatic acid is poured upon it, owing to the rapid emission of phosphureted hydrogen gas †.

Action of metals

8. Lime does not combine with azote; but it unites readily with muriatic acid, and forms muriat of lime.

9. Lime facilitates the oxidizement of several of the

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* Van Mons has proposed the following method; but it appears to me rather inferior to that which is described in the text:—Fill a small glass matrass two-thirds with carbonat of lime in powder. Put it into a sand bath, and expose it to a heat sufficient to drive off the carbonic acid. Towards the end of the process introduce gradually a third part of phosphorus, taking care to keep the lime in a red heat. The phosphorus melts, but is prevented from burning by the remains of carbonic acid, which it disengages from the lime. When the whole of the phosphorus is introduced, shut up the matrass with a stopper, provided with a valve to let gas escape, but permit none to enter, and let the fire be immediately withdrawn. When quite cold, the phosphuret is to be put into dry phials with ground stoppers. See *Jour. de Chim.* iii. 75.

† Fourcroy, ii. 172.

metals, and it combines with several of the metallic oxides, and forms salts which have not hitherto been examined, if we except the compounds which it forms with the oxides of mercury and lead, which have been described by Berthollet.

And their oxides.

The red oxide of mercury, boiled with lime-water, is partly dissolved, and the solution yields by evaporation small transparent yellow crystals *. This compound has been called by some *mercuriat of lime.*

Lime-water also dissolves the red oxide of lead, and (still better) litharge. This solution, evaporated in a retort, gives very small transparent crystals, forming prismatic colours, and not more soluble in water than lime. It is decomposed by all the alkaline sulphats, and by sulphureted hydrogen gas. The sulphuric and muriatic acids precipitate the lead. This compound blackens wool, the nails, the hair, white of eggs; but it does not affect the colour of silk, the skin, the yolk of egg, nor animal oil. It is the lead which is precipitated on these coloured substances in the state of oxide; for all acids can dissolve it. The simple mixture of lime and oxide of lead blackens these substances; a proof that the salt is easily formed †.

10. Lime does not combine with alkalies, nor with the two earths already described.

Affinities.

The affinities of lime are arranged by Bergman in the following order:

Oxalic acid,
Sulphuric,
Tartaric,

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* Berthollet, *Ann. de Chim.* i. 61.

† Ibid. 52

Succinic,
Phosphoric,
Saclactic,
Nitric,
Muriatic,
Suberic,
Fluoric,
Arsenic,
Lactic,
Citric,
Benzoic,
Sulphurous,
Acetic,
Boracic,
Carbonic,
Prussic.

Of mortar.

One of the most important uses of lime is the formation of *mortar* as a cement in building. Mortar is composed of quicklime and sand reduced to a paste with water. When dry it becomes as hard as stone, and as durable; and adhering very strongly to the surfaces of the stones which it is employed to cement, the whole wall becomes in fact nothing else than one single stone. But this effect is produced very imperfectly unless the mortar be very well prepared.

The lime ought to be pure, completely free from carbonic acid, and in the state of a very fine powder: the sand should be free from clay, and partly in the state of fine sand, partly in that of gravel: the water should be pure; and if previously saturated with lime so much the better. The best proportions, according to the experiments of Dr Higgins, are three parts of fine sand, four parts of coarser sand, one part of quicklime recently slacked, and as little water as possible.

The stony consistence which mortar acquires is owing, partly to the absorption of carbonic acid, but principally to the combination of part of the water with the lime. This last circumstance is the reason that if to common mortar one fourth part of lime, reduced to powder without being slacked, be added, the mortar when dry acquires much greater solidity than it otherwise would do. This was first proposed by Loriot[*]; and a number of experiments were afterwards made by Morveau[†]. The proportions which this philosopher found to answer best are the following.

Fine sand	0.3
Cement of well baked bricks	0.3
Slacked lime	0.2
Unslacked lime	0.2
	1.0

The same advantages may be attained by using as little water as possible in slacking the lime. This was first pointed out by La Faye[‡].

Higgins found that the addition of burnt bones improved mortar by giving it tenacity, and rendering it less apt to crack in drying; but they ought never to exceed one fourth of the lime employed.

When a little manganese is added to mortar, it acquires the important property of hardening under water; so that it may be employed in constructing those edifices which are constantly exposed to the action of

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[*] *Jour. de Phys.* iii. 231.

[†] Ibid. vi. 311.

Ibid. ix. 437.

water. Limestone is found not unfrequently combined with manganese; and in that case it becomes brown by calcination, instead of white. These native limestones are employed for making *water mortar;* but good water mortar may be made by the following process, first proposed by Morveau: Mix together 4 parts of blue clay, 6 parts of black oxide of manganese, and 90 parts of limestone, all in powder. Calcine this mixture to expel the carbonic acid, mix it with 60 parts of sand, and form it into mortar with a sufficient quantity of water *.

The best mortar for resisting water is made by mixing with lime puzzollano, a volcanic sand brought from Italy. Morveau informs us that *basaltes,* which is very common in this country, may be substituted for puzzollano. It must be heated in a furnace, thrown while red hot into water, and then passed through a sieve to reduce it to the proper size †.

SECT. IV.

OF MAGNESIA.

History.

ABOUT the beginning of the eighteenth century, a Roman canon exposed a white powder to sale at Rome as a cure for all diseases. This powder he called *magnesia alba.* He kept the manner of preparing it a pro-

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* *Ann. de Chim.* xxvii. 259.

† Ibid. 262.

found secret; but in 1707 Valentini informed the public that it might be obtained by calcining the lixivium which remains after the preparation of nitre *; and two years after, Slevogt discovered that it might be precipitated by potass from the mother ley † of nitre ‡. This powder was generally supposed to be *lime* till Frederic Hoffman observed that it formed very different combinations with other bodies ¶. But little was known concerning its nature, and it was even confounded with lime by most chemists, till Dr Black made his celebrated experiments on it in 1755. Margraff published a dissertation on it in 1759 §, and Bergman another in 1775, in which he collected the observations of these two philosophers, and which he enriched also with many additions of his own ‖. Butini of Geneva likewise published a valuable dissertation on it in 1779.

Preparation.

1. As magnesia has never yet been found native in a state of purity, it may be prepared in the following manner: *Sulphat of magnesia*, a salt composed of this earth and sulphuric acid exists in sea water, and in many springs, particularly in some about Epsom; from which circumstance it was formerly called *Epsom salt*. This salt is to be dissolved in water, and half its weight of potass added. The magnesia is immediately precipitated, because potass has a stronger affinity for sulphu-

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* *De Magnesia Alba.*

† The *mother ley* is the liquid that remains after as much as possible of any salt has been obtained from it. Common salt, for instance, is obtained by evaporating sea water. After as much salt has been extracted from a quantity of sea water as will crystallize, there is still a portion of liquid remaining. This portion is the mother ley.

‡ *Diss. de Magnesia Alba.*

¶ *Obs. Phys. Chim.* 1722. p. 115. and 194.

§ *Opusc.* ii. 20.

‖ *Ibid.* i. 365.

ric acid. It is then to be washed with a sufficient quantity of water, and dried.

Properties.

2. Magnesia thus obtained is a very soft white powder, which has very little taste, and is totally destitute of smell. Its specific gravity is about 2.3 *. It converts delicate vegetable blues (paper, for instance, stained with the petals of the mallow) to green.

It is not melted by the strongest heat which it has been possible to apply; but Mr Darcet observed that, in a very high temperature, it became somewhat agglutinated. When formed into a cake with water, and then exposed to a violent heat, the water is gradually driven off, and the magnesia contracts in its dimension; as the same time, as Mr Tingry informs us, it acquires the property of shining in the dark when rubbed upon a hot iron plate.

Action of water,

3. It is almost insoluble in water; for, according to Mr Kirwan, it requires 7900 times its weight of water at the temperature of 60° to dissolve it. It is capable, however, of combining with water in a solid state, like the three earths already described; for 100 parts of magnesia, thrown into water, and then dried, are increased in weight to 118 parts †. Even when combined with carbonic acid (for which it has a strong affinity) it is capable of absorbing and retaining $1\frac{1}{2}$ times its own weight of water without letting go a drop; but on exposure to the air, this water evaporates, though more slowly than it would from lime.

Magnesia has never yet been obtained in a crystallized form.

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* Kirwan's *Miner.* i. 8.

† Bergman, i. 371.

When expossd to the air, it attracts carbonic acid gas and water; but exceedingly slowly. Butini left a quantity of it for two years in a porcelain cup merely covered with paper; its weight was only increased $\frac{1}{145}$ part.

Oxygen,

4. Magnesia does not combine with oxygen; nor is it altered by any of the compounds into which oxygen enters.

Simple combustibles,

5. The only one of the simple combustibles with which it can be united is sulphur. No person has hitherto succeeded in forming a phosphuret of magnesia. In this respect it differs from the three earths already described.

The sulphuret of magnesia may be formed by exposing a mixture of two parts of magnesia and one part of sulphur to a gentle heat in a crucible. The result is a yellow powder, slightly agglutinated, which emits very little sulphureted hydrogen gas when thrown into water. A moderate heat is sufficient to drive off the sulphur *.

Incombustibles,

6. Magnesia does not combine with azote, but it unites with muriatic acid, and forms a compound called *muriat of magnesia.*

Metals,

7. Magnesia has no action upon the metals; nor does it combine, as far as is known at present, with the metallic oxides, unless some intermediate substance be present.

Alkalies,

8. Magnesia does not combine with the fixed alkalies, neither are its properties altered by these bodies: but it has a strong propensity to enter into triple compounds with ammonia.

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* Fourcroy, ii. 165.

9. Neither does magnesia combine with any of the three preceding earths.

And earths.

There seems to be little affinity between magnesia and barytes; at least no mixture of the two earths is fusible in the strongest heat which it has been possible to apply *. Morveau indeed affirmed, that muriat of barytes, and muriat of magnesia, occasion a precipitate when mixed together †. But Darracq and Chenevix have shewn, that this was owing to the impurity of the salts, and that when free from all foreign bodies, no precipitation takes place.

Mr Kirwan has shown that there is but little affinity between strontian and magnesia. They do not melt when exposed to a strong heat, at least when the strontian exceeds or equals the magnesia ‡.

Equal parts of lime and magnesia, mixed together, and exposed by Lavoisier to a very violent heat, did not melt; neither did they melt when Mr Kirwan placed them in the temperature of 150° Wedgewood The following Table, drawn up by Mr Kirwan from his own experiments, shews the effect of heat on these two earths mixed together in different proportions.

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* Lavoisier, *Mem. Par.* 1782.

† Morveau, *Ann. de Chim.* xxxi 53

‡ *Irish Trans.* v. 246, 247.

Proportions.	Heat.	Effect.
80 Lime 20 Mag.	150° Wedg	Went through the crucible.
75 Lime 25 Mag.	160	Went through the crucible.
66 Lime 33 Mag.		Went through the crucible.
20 Lime 80 Mag.	165	Did not melt.
33 Lime 66 Mag.	138	Did not melt.
30 Lime 10 Mag.	156	Melted into a fine greenish yellow glass; but the crucible was corroded throughout.

Affinities.

10. The affinities of magnesia, according to Bergman, are as follows :

Oxalic acid,
Phosphoric,
Sulphuric,
Fluoric,
Arsenic,
Saclactic,
Succinic,
Nitric,
Muriatic,
Tartaric,
Citric,
Lactic,
Benzoic,

Acetic,
Boracic,
Sulphurous,
Carbonic,
Prussic.

Magnesia is used only in medicine. It is administered internally to remove acidity in the stomach.

SECT. V.

OF ALUMINA.

History.

ALUM is a salt which was well known to the ancients, and employed by them in dyeing, but they were ignorant of its component parts. The alchymists discovered that it is composed of sulphuric acid and an earth; but the nature of this earth was long unknown. Stahl and Neumann supposed it to be lime; but in 1727 Geoffroy junior proved this to be a mistake, and demonstrated, that the earth of alum constitutes a part of clay *. In 1754, Margraff showed that the basis of alum is an earth of a peculiar nature different from every other; an earth which is an essential ingredient in clays, and gives them their peculiar properties †. Hence this earth was called *argill*; but Morveau afterwards gave it the name of *alumina*, because it is obtained in the state

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* *Mem. Par.* 1727.

† *Mem. Berlin*, 1754 and 1759, Margraff, ii. 1.

of greatest purity from alum. The properties of alumina were still farther examined by Macquer in 1758 and 1762 *, by Bergman in 1767 and 1771 †, and by Scheele in 1776 ‡; not to mention several other chemists who have contributed to the complete investigation of this earth. A very ingenious treatise on it was published by Saussure, junior, in 1801 §.

Preparation.

1. Alumina may be obtained by the following process: Dissolve alum in water, and add to the solution ammonia as long as any precipitate is formed. Decant off the fluid part, and wash the precipitate in a large quantity of water, and then allow it to dry. The substance thus obtained is *alumina*; not however in a state of absolute purity, for it still retains a portion of the sulphuric acid, with which it was combined in the alum. But it may be rendered tolerably pure by dissolving the newly precipitated earth in muriatic acid; evaporating the solution till a drop of it in cooling deposites small crystals; setting it by to crystallize, separating the crystals; concentrating the liquid a second time, and separating the crystals which are again deposited. By this process, most of the alum which the earth retained will be separated in crystals. If the liquid be now mixed with ammonia as long as any precipitate appears, this precipitate, washed and dried, will be *alumina* nearly pure **.

The earth thus obtained assumes two very different appearances according to the way in which the precipi-

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* *Mem. Paris.*

† Bergm. i. 287. and v. 71.

‡ Scheele, i. 191. French Transl.

§ *Jour. de Phys.* lii. 2

** Accum's *chemistry*, ii. 198.

tation has been conducted. If the earthy salt be dissolved in as little water as possible, the alumina has the appearance of a white earth, light, friable, very spongy, and attaching itself strongly to the tongue. In this state Saussure distinguishes it by the name of *spongy alumina*.

But if the salt has been dissolved in a great quantity of water, the alumina is obtained in a brittle transparent yellow-coloured mass, splitting in pieces like roll sulphur when held in the hand. Its fracture is smooth and conchoidal; it does not adhere to the tongue, and has not the common appearance of an earthy body. In this state Saussure gives it the name of *gelatinous alumina* [*].

Properties.

2. Alumina has little taste: when pure, it has no smell; but if it contains oxide of iron, which it often does, it emits a peculiar smell when breathed upon, known by the name of *earthy smell* [†]. This smell is very perceptible in common clays. The specific gravity of alumina is 2.00 [‡].

Contracted by heat.

3. When heat is applied to alumina it gradually loses weight, in consequence of the evaporation of a quantity of water with which, in its usual state, it is combined, at the same time its bulk is considerably diminished. The spongy alumina parts with its moisture very readily, but the gelatinous retains it very strongly. Spongy alumina, when exposed to a red heat, loses 0.58 parts of its weight; gelatinous, only 0.43: Spongy alumina loses no more than 0.58 when exposed to a heat of

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[*] *Jour. de Phys.* lii. 290.

[†] Saussure, *Jour. de Phys.* lii. 287.

[‡] Kirwan's *Miner.* i. 1.

130° Wedgewood: Gelatinous in the same temperature loses but 0.4825. Yet Saussure has shown that both species, after being dried in the temperature of 60°, contain equal proportions of water *.

Alumina undergoes a diminution of bulk proportional to the heat to which it is exposed. This contraction seems owing, in low temperatures, to the loss of moisture: but in high temperatures it must be owing to a more intimate combination of the earthy particles with each other; for it loses no perceptible weight in any temperature, however high, after being exposed to a heat of 130° Wedgewood †.

Wedgewood's pyrometer.

Mr Wedgewood took advantage of this property of alumina, and by means of it constructed an instrument for measuring high degrees of heat. It consists of pieces of clay of a determinate size, and an apparatus for measuring their bulk with accuracy: One of these pieces is put into the fire, and the temperature is estimated by the contraction of the piece ‡. The contraction of the clay-pieces is measured by means of two brass rules fixed upon a plate. The distance between which at one extremity is 0.5 inch, and at the other extremity 0.3 inch, and the rules are exactly 24.0 inches in length, and divided into 240 equal parts called degrees. These degrees commence at the widest end of the scale. The first of them indicates a red heat, or 947° Fahrenheit. The clay-pieces are small cylinders, baked in a red heat, and made so as to fit 1° of the

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* Kirwan's *Miner.* i. p. 291.

† Ibid.

‡ See a particular description of this thermometer in *Phil. Trans.* lxii. and lxiv.

scale. They are not composed of pure alumina, but of a fine white clay.

Unfortunately the contraction of these pieces is not always proportional to the degree of heat to which they have been exposed, nor do they correspond exactly with each other. The instrument, notwithstanding, is certainly valuable, and has contributed considerably towards the extension of our knowledge.

Alumina, when exposed to a very violent heat, produced by directing a stream of oxygen gas upon burning charcoal, undergoes a commencement of fusion, and is converted into a white enamel, semitransparent and excessively hard *. If we put any confidence in the calculation of Saussure, the temperature necessary for producing this effect is as high as 1575° Wedgewood †.

4. Alumina is scarcely soluble in water, but may be diffused through that liquid with great facility. Its affinity for water, however, is very considerable. In its usual state it is combined with more than its own weight of water, and we have seen with what obstinacy it retains it. Even this combination of alumina and water is capable, in its usual state of dryness, of absorbing 2½ times its weight of water, without suffering any to drop out. It retains this water more obstinately than any of the earths hitherto described. In a freezing cold it contracts more, and parts with more of its water, than any other earth; a circumstance which is of some importance in agriculture ‡.

Alumina has no effect upon vegetable blues. It can-

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* Morveau, *Jour. de l'Ecole Polytechnique*, I. iii. 299.

† *Jour. de Phys.* 1794.

‡ Kirwan's *Miner.* i. 9

not be crystallized artificially; but it is found native in beautiful transparent crystals, exceedingly hard, and having a specific gravity of 4. It is distinguished in this state by the name of *sapphyr*.

Action of oxygen,

5. Alumina, as far as is known at present, is not affected by light, neither does it combine with oxygen.

Combustibles,

6. None of the simple combustibles are capable of uniting with it. Charcoal indeed combines with it, and forms a black compound *, which is frequently found native.

Incombustibles,

7. It is not acted upon by azote, but muriatic acid dissolves it, and forms with it an uncrystallizable compound called muriat of alumina.

Metals,

8. It does not combine with metals, but it has a strong affinity for metallic oxides, especially for those oxides which contain a maximum of oxygen. Some of these compounds are found native. Thus, the combiniation of alumina and red oxide of iron often occurs in the form of a yellow powder, which is employed as a paint, and distinguished by the name of *ochre*.

Alkalies,

9. There is a strong affinity between the fixed alkalies and alumina. When heated together, they combine and form a loose mass without any transparency. Liquid fixed alkali dissolves alumina by the assistance of heat, and retains it in solution. The alumina is precipitated again unaltered, by dropping an acid into the solution. This is a method employed by chemists to procure alumina in a state of complete purity; for alumina, unless it be dissolved in alkali, almost always retains a little oxide of iron and some acid, which disguise its proper-

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* Nicholson's *Journal*, ii. 101.

ties. Liquid ammonia is also capable of dissolving a very minute proportion of newly precipitated alumina.

Barytes and strontian,

10. Barytes and strontian also combine with alumina, both when heated with it in a crucible, and when boiled with it in water. The result, in the first case, is a greenish or bluish-coloured mass, cohering but imperfectly: in the second, two compounds are formed; the first, containing an excess of alumina, remains in the state of insoluble powder; the other, containing an excess of barytes or strontian, is held in solution by the water *.

Lime.

Alumina has a strong affinity for lime, and readily enters with it into fusion. The effect of heat on various mixtures of lime and alumina will appear from the following TABLE †.

Proportions.	Heat.	Effect.
75 Lime 25 Alumina	150° Wedg.	Not melted.
66 Lime 33 Alumina	150	Remained a powder.
33 Lime 66 Alumina	‡	Melted.
25 Lime 75 Alumina	‡	Melted.
20 Lime 80 Alumina	‡	Melted.

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[*] Vauquelin, *Ann. de Chim.* xxix. 270.

[†] Kirwan, i. 65.

[‡] These three experiments were made by Ehrman: The heat was produced by directing a stream of oxygen gas on burning charcoal, and is the most intense which it has been hitherto possible to produce.

Magnesia.

Magnesia and alumina have no action whatever on each other, even when exposed to a heat of 150° Wedgewood *.

From the experiments of Achard, it appears, that no mixture of lime, magnesia, and alumina, in which the lime predominates, is vitrifiable, except they be nearly in the proportions of three parts lime, two magnesia, one alumina; that no mixture in which magnesia predominates will melt in a heat below 166°; that mixtures in which that alumina exceeds are generally fusible, as will appear from the following TABLE †.

3 Alumina 2 Lime 1 Magnesia	A porcelain.
3 Alumina 1 Lime 2 Magnesia	A porcelain.
3 Alumina 1 Lime 3 Magnesia	Porous porcelain.
3 Alumina 2 Lime 3 Magnesia	Porous porcelain.
3 Alumina 2 Lime 2 Magnesia	Porcelain.

Affinities.

The affinities of alumina are as follows:

Sulphuric acid,
Nitric,

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* Kirwan's *Miner.* i. 57.

† Ibid. p. 72.

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Muriatic,
Oxalic,
Arsenic,
Fluoric,
Tartaric,
Succinic,
Saclactic,
Citric,
Phosphoric,
Lactic,
Benzoic,
Acetic,
Boracic,
Sulphurous,
Carbonic,
Prussic.

None of the earths is of more importance to mankind than alumina; it forms the basis of china and stoneware of all kinds, and of the crucibles and pots employed in all those manufactures which require a strong heat. It is absolutely necessary to the dyer and calico-printer, and is employed too with the greatest advantage by the fuller and cleaner of cloth.

SECT. VI.

OF YTTRIA.

History.

Some time before 1788, Captain Arhenius discovered in the quarry of Ytterby in Sweden a peculiar mineral different from all those described by mineralogists. Its colour is greenish black, and its fracture like that of glass. It is magnetic and generally too hard to be scratched by a knife. It is opaque, except in small pieces, when it transmits some yellow rays. Its specific gravity is 4.237[*]. A description of it was published by Geyer in 1788 in Crell's Annals, and by Rinman in his Miner's Lexicon. Professor Gadolin analysed this mineral in 1794, and found it to contain a new earth: but though his analysis was published in the Stockholm Transactions for 1794, and in Crell's Annals for 1796, it was some time before it drew the attention of chemical mineralogists. The conclusions of Gadolin were confirmed by Ekeberg in 1797, who gave to the new earth the name of *yttria*[†]. They were still farther confirmed and extended by Vauquelin in 1800[‡], and likewise by Klaproth about the same time[§]; and Ekeberg has published a new dissertation on the subject in the Swedish Transactions for 1802[||]. We may therefore consider the peculiar nature of yttria as sufficiently established.

Preparation.

1. Hitherto yttria has been found only in the black mineral first analysed by Gadolin, and hence called *Gadolinite*, in which it is combined with black oxide of iron and the earth called silica; and in yttrotantalite, which from the description of Ekeberg is a compound of tantalium and yttria. Both of these minerals occur only in the quarry of Ytterby. From the first, which is the most common, the earth may be procured by treat-

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[*] Gadolin, Crell's *Annals*, 1796, i. 313.—Vauquelin, *Ann. de Chim.* xxxvi. 146.—Klaproth's *Beitrage*, iii. 58.

[†] Crell's *Annals*, 1799, ii. 63.

[‡] *Ann. de Chim.* xxxvi. 143

[§] Ibid. xxxvii. 86. and *Beitrage*, iii. 52.

[||] *Jour. de Chim.* iii. 78.

ing the mineral reduced to powder with a mixture of nitric and muriatic acids, till it is completely decomposed; then filtering the solution, previously evaporated nearly to dryness, and then diluting it with water. By this process the silica is left behind. The liquid which passes through the filter is to be evaporated to dryness, and the residue heated to redness for a considerable time in a close vessel, and then redissolved in water and filtered. What passes through the filter is colourless; when treated with ammonia, pure yttria falls.

Properties.

2. Yttria, thus procured, has the appearance of a fine white powder, and has neither taste nor smell. It is not melted by the application of heat. It has no action on vegetable blues. It is much heavier than any of the other earths; its specific gravity, according to Ekeberg, being no less than 4.842.

It is insoluble in water; yet it is capable of retaining a great proportion of that liquid, as is the case with alumina. Klaproth ascertained, that 100 parts of yttria precipitated from muriatic acid by ammonia, and dried in a low temperature, lose 31 parts, or almost a third of their weight, when heated to redness in a crucible. Now this last consists of pure water alone.

It is not soluble in pure alkalies; but it dissolves readily in carbonat of ammonia, and in all the other alkaline carbonats. It combines with acids, and forms with them salts which have a sweet taste, and at the same time a certain degree of austerity. Some of these salts have a red colour. Yttria is the only earthy body known which has the property of forming coloured salts with acids.

3. Yttria is not altered by light, nor is it likely that it combines with oxygen. From the experiments of

Klaproth, it does not appear to combine readily with sulphur; nor is it likely that it unites with any of the other simple combustibles.

We may take it for granted that it is not affected by azote; but it combines with muriatic acid, and forms a salt not capable of crystallizing. Its action on the metals and metallic oxides is unknown.

SECT. VII.

OF GLUCINA.

History.

THE beryl is a transparent stone, of a green colour, and a considerable degree of hardness, which is found crystallized in the mountains of Siberia, and in many other parts. Vauquelin analysed this mineral in 1798, at the request of Hauy, to determine whether it was formed of the same ingredients with the emerald, as Hauy had conjectured from mineralogical considerations. The result of the analysis was a confirmation of the suspicions of Hauy, and the discovery of a new earth, to which Vauquelin and his associates gave the name of *glucina**. The experiments of Vauquelin have been repeated by Klaproth † and other eminent chemists.

Preparation.

1. To obtain glucina pure, the beryl or the emerald, reduced to powder, is to be fused with thrice its weight of potass. The mass is to be diluted with water, dis-

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* *Ann. de Chim.* xxvi. 155.

† *Beitrage*, iii 315.

solved in muriatic acid, and the solution evaporated to dryness. The residuum is to be mixed with a great quantity of water, and the whole thrown on a filter. The silica, which constitutes more than half the weight of the stone, remains behind; but the glucina and the other earths, being combined with muriatic acid, remain in solution. Precipitate them by means of carbonat of potass. Wash the precipitate, and then dissolve it in sulphuric acid. Add to the solution sulphat of potass; evaporate it to the proper consistency, and set it by to crystallize. Alum crystals gradually form. When as many of these as possible have been obtained, pour into the liquid carbonat of ammonia in excess, then filter, and boil the liquid for some time. A white powder gradually appears, which is *glucina*.

Properties.

2. Glucina, thus obtained, is a soft light white powder, without either taste or smell; which has the property of adhering strongly to the tongue. It has no action on vegetable colours. It is altogether infusible by heat; neither does it harden or contract in its dimensions, as is the case with alumina. Its specific gravity is 2.967[*].

It is insoluble in water, but forms with a small quantity of that liquid a paste which has a certain degree of ductility.

3. It does not combine with oxygen nor with any of the simple combustibles; but sulphureted hydrogen dissolves it, and forms with it a hydrosulphuret, similar to other hydrosulphurets in its properties[†].

4. Azote has no action on it; but muriatic acid dis-

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[*] Ekeberg, *Ann. de Chim.* xliii. 277.

[†] Fourcroy, ii. 159.

solves it, and forms with it a sweet tasted salt, called *muriat of glucina*.

5. Glucina is soluble in the liquid fixed alkalies, in which it agrees with alumina. It is insoluble in ammonia, but soluble in carbonat of ammonia, in which respect it agrees with yttria; but it is about five times more soluble in carbonat of ammonia than that earth.

It combines with all the acids, and forms with them sweet tasted salts[*], as is the case also with yttria.

SECT. VIII.

OF ZIRCONIA.

History.

AMONG the precious stones which come from the island of Ceylon, there is one called *jargon* or *zircon*, which is possessed of the following properties.

Its colour is various; grey, greenish-white, yellowish, reddish-brown, and violet. It is often crystallized, either in right angular quadrangular prisms surmounted with pyramids, or octahedrons consisting of double quadrangular pyramids. It has generally a good deal of lustre, at least internally. It is mostly semitransparent. Its hardness is from 10 to 16: Its specific gravity from 4.416 to 4.7 .

It loses scarcely any of its weight in a melting heat;

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[*] Hence the name *glucina*, from γλυκες, *sweet.*

[†] Kirwan's *Min.* i. 333.

for Klaproth, who analysed it in 1789, found, that 300 grains, after remaining in it for an hour and a half, were only one-fourth of a grain lighter than at first*. Neither was it attacked either by muriatic or sulphuric acid, even when assisted by heat. At last, by calcining it with a large quantity of soda, he dissolved it in muriatic acid, and found that 100 parts of it contained 31.5 of silica, 0.5 of a mixture of nickel and iron, and 68 of a new earth, possessed of peculiar properties, which has received the name of *zirconia* from the mineral in which it was detected. Owing probably to the scarcity of the zircon, nobody attempted to repeat the analysis of Klaproth, or to verify his discovery. In 1795 he published his analysis of the *hyacinth*, another mineral from the same island, in which he also detected a large proportion of zirconia, expressing his hopes that it would induce chemists to turn their attention to the subject†. This analysis induced Guyton-Morveau in 1796 to examine the hyacinths of Expailly in France. They proved similar to the hyacinths of Ceylon, and contained the proportion of zirconia indicated by Klaproth‡. These experiments were soon after repeated, and the nature of the new earth still farther examined by Vauquelin§.

Preparation.

1. Zirconia has hitherto been found only in the zircon and hyacinth. It may be obtained pure by the following process: Reduce the mineral to powder, mix it with thrice its weight of potass, and fuse it in a crucible. Wash the mass in pure water till the whole of

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[*] *Jour. de Phys.* xxxvi. 180.

[†] Beitrage, i. 231.

[‡] *Ann. de Chim.* xxi. 72.

[§] Ibid xxii. 158. and *Jour. de Min.* An. v. 97.

the potass is extracted; then dissolve the residuum as far as possible in diluted muriatic acid. Boil the solution to precipitate any silica which may have been dissolved; then filter, and add a quantity of potass. The zirconia precipitates in the state of a fine powder.

Properties.

2. Zirconia, thus prepared, has the form of a fine white powder, which feels somewhat harsh when rubbed between the fingers. It has neither taste nor odour. It is infusible before the blow-pipe; but when heated violently in a charcoal crucible, it undergoes a kind of imperfect fusion, acquires a grey colour, and something of the appearance of porcelain. In this state it is very hard, its specific gravity is 4.3, and it is no longer soluble in acids.

Zirconia is insoluble in water; but it has a considerable affinity for that liquid. When dried slowly, after being precipitated from a solution, it retains about the third of its weight of water, and assumes a yellow colour, and a certain degree of transparency, which gives it a great resemblance to gum arabic*.

3. It does not combine with oxygen, simple combustibles, azote, nor metals; but it has a strong affinity for several metallic oxides, especially for oxide of iron, from which it is very difficult to separate it.

It is insoluble in liquid alkalies, neither can it be fused along with them by means of heat; but it is soluble in alkaline carbonats.

4. Scarcely any experiments have been made to ascertain its affinity for the different earths. It is known, however, that a mixture of alumina and zirconia is capable of fusion.

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* Vauquelin, *Ann. de Chim.* xxii. 158.

Chap. II.

Zirconia combines with all the acids, and forms salts, which have a peculiar astringent taste, and are many of them insoluble in water. The order of its affinities, as far as it has been ascertained, is as follows:

Vegetable acids,
Sulphuric,
Muriatic,
Nitric.

This earth has not hitherto been applied to any use. Its scarcity, and the difficulty of procuring it in a state of purity, exclude it at present from any chance of being employed for the purposes of domestic economy.

SECT. IX.

OF SILICA.

History.

THERE is a very hard white stone, known by the name of *quartz*, very common in almost every part of the world. Sometimes it is transparent and crystallized, and then is called *rock crystal*. Very frequently it is in the form of sand. As this stone, and several others which resemble it, as flint, agate, calcedony, &c. have the property of melting into a glass when heated along with fixed alkali, they were classed together by mineralogists under the name of *vitrifiable stones*. Mr Pott, who first described their properties in 1746, gave them the name of *siliceous stones*, on the supposition that they were all chiefly composed of a peculiar earth called *siliceous* earth or *silica*. This earth was known to Glauber, who describes the method of obtaining it: but it was long before its properties were accurately ascertained. Geoffroy[*] endeavoured to prove that it might be converted into lime, and Pott[†] and Beaumé[‡] that it might be converted into alumina: but these assertions were refuted by Cartheuser[§], Scheele[||], and Bergman[¶]. To this last chemist we are indebted for the first accurate detail of the properties of silica[**].

Preparation.

1. Silica may be obtained pure by the following process: Mix together, in a crucible, one part of pounded flint or quartz, and three parts of potass, and apply a heat sufficient to melt the mixture completely. Dissolve the mass formed in water, saturate the potass with muriatic acid, and evaporate to dryness. Towards the end of the evaporation the liquid assumes the form of a jelly; and when all the moisture is evaporated, a white mass remains behind. This mass is to be washed in a large quantity of water and dried; it is then silica in a state of purity.

Properties.

2. Silica, thus obtained, is a fine white powder, without either taste or smell. Its particles have a harsh feel, as if they consisted of very minute grains of sand. Its specific gravity is 2.66[††].

It may be subjected to a very violent heat without undergoing any change. Lavoisier and Morveau exposed it to the action of a fire maintained by oxygen gas

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[*] *Mem. Par.* 1746, p. 286.

[†] *Lithogn.* p. 3. Præf.

[‡] *Man. de Chym.*

[§] *Miner. Abh.*

[||] Scheele. i. 191.

[¶] *Sur les Terres Geoponiques,* 1773, *Opusc.* v. 59.

[**] *Opusc.* ii. 26.

[††] Kirwan's *Min.* i. 10.

without any alteration[*]. Saussure indeed has succeeded in fusing, by means of the blow-pipe, a portion of it so extremely minute as scarcely to be perceptible without a glass. According to the calculation of this philosopher, the temperature necessary for producing this effect is equal to 4043° Wedgewood.

Action of water.

3. It is insoluble in water except when newly precipitated, and then one part of it is soluble in 1000 parts of water[†]. It has no effect on vegetable colours.

It is capable of absorbing about one-fourth of its weight of water, without letting any drop from it; but on exposure to the air, the water evaporates very readily[‡]. When precipitated from potass by means of muriatic acid and slow evaporation, it retains a considerable portion of water, and forms with it a transparent jelly; but the moisture gradually evaporates on exposure to the air.

Silica may be formed into a paste with a small quantity of water: this paste has not the smallest ductility, and when dried forms a loose, friable, and incoherent mass[§].

Silica is capable of assuming a crystalline form. Crystals of it are found in many parts of the world. They are known by the name of *rock crystal.* When pure they are transparent and colourless like glass: they assume various forms; the most usual is a hexagonal prism, surmounted with hexagonal pyramids on one or both ends, the angles of the prism corresponding with those of the pyramids. Their hardness is ve-

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[*] *Jour. de l'Ecole Polytechn.* I. iii. 299.

[†] Kirwan's *Min.* i. 10.

[‡] Ibid.

[§] Scheele

ry great, amounting to 11. Their specific gravity is 2.655 [*].

There are two methods of imitating these crystals by art. The first method was discovered by Bergman. He dissolved silica in fluoric acid, and allowed the solution to remain undisturbed for two years. A number of crystals were then found at the bottom of the vessel, mostly of irregular figures, but some of them cubes with their angles truncated. They were hard, but not to be compared in this respect with rock crystal [†].

The other method was discovered by accident. Professor Seigling of Erfurt had prepared a liquor silicum, which was more than usually diluted with water, and contained a superabundance of alkali. It lay undisturbed for eight years in a glass vessel, the mouth of which was only covered with paper. Happening to look to it by accident, he observed it to contain a number of crystals; on which he sent it to Mr Trommsdorf, professor of chemistry at Erfurt, who examined it. The liquor remaining amounted to about two ounces. Its surface was covered by a transparent crust, so strong that the vessel might be inverted without spilling any of the liquid. At the bottom of the vessel were a number of crystals, which proved on examination to be sulphat of potass and carbonat of potass [‡]. The crust on the top consisted partly of carbonat of potass, partly of crystallized silica. These last crystals had assumed the form of tetrahedral pyramids in groups; they were perfectly transparent, and so hard that they struck fire with steel [§].

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[*] Kirwan's *Min.* i. 242.

[†] Bergman, ii. 32.

[‡] Potass combined with sulphuric acid and carbonic acid.

[§] Nicholson's *Journal*, i. 217.

Action of simple substances.

4. Silica neither combines with oxygen, with the simple combustibles, nor with metals; but it combines with many of the metallic oxides by fusion, and forms various coloured glasses and enamels.

5. Azote has no action on silica; neither has muriatic acid when the silica is in a solid state; but when the silica is combined with an excess of alkali, muriatic acid dissolves the compound, and forms a permanent solution. By concentrating this solution, the silica separates from it in the form of a jelly.

Action of alkalies,

6. There is a strong affinity between silica and fixed alkalies. It may be combined with them either by fusing them along with it in a crucible, or by boiling the liquid alkalies over it. When the potass exceeds the silica considerably, the compound is soluble in water, and constitutes what was formerly called *liquor silicum*, and now sometimes *silicated potass* or *soda*. When the silica exceeds, the compound is transparent and colourless like rock crystal, and is neither acted on by water, air, nor (excepting one) by acids. This is the substance so well known under the name of *glass*.

Silica is not acted on by ammonia, whether in the gaseous or liquid state.

Of barytes,

7. There is a strong affinity between barytes and silica. When barytes water is poured into a solution of silica in potass, a precipitate appears, which is considered by Morveau as the two earths in a state of combination *. Barytes and silica may be combined by means of heat. The compound is of a greenish colour, and

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* Morveau, *Ann. de Chim.* xxxi. 250.

coheres but imperfectly *. The effect of heat on various mixtures of barytes and silica will appear from the following experiments of Mr Kirwan †.

Proportions.	Heat.	Effect.
80 Silica 20 Barytes	155° Wedg.	A white brittle mass.
75 Silica 20 Barytes	150	A britle hard mass, semi-transparent at the edges.
66 Silica 33 Barytes	150	Melted into a hard somewhat porous porcelain mass.
50 Silica 50 Barytes	148	A hard mass not melted.
20 Silica 80 Barytes	148	The edges were melted into a pale greenish matter between a porcelain and enamel.
25 Silica 75 Barytes	150	Melted into a somewhat porous porcelain mass.
33 Silica 66 Barytes	150	Melted into a yellowish and partly greenish white porous porcelain.

Strontian,

Strontian and silica combine with each other nearly in the same manner.

Lime,

There is also an affinity between silica and lime,

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* Vauquelin, *Ann. de Chim.* xxix. 271.

† Kirwan's *Min.* i. 57.

When lime-water is poured into a solution of silica in potass, a precipitate appears, as Stucke discovered. This precipitate is a compound of silica and lime *. These two earths may be combined also by means of heat. They form a glass, provided the quantity of lime be not inferior to that of silica. The effect of heat upon these earths, mixed in various proportions, will appear from the following experiments of Mr Kirwan †.

Proportions.	Heat.	Effect.
50 Lime 50 Silica	150° Wedg.	Melted into a mass of a white colour, semitransparent at the edges, and striking fire, though feebly, with steel: it was somewhat between porcelain and enamel.
80 Lime 20 Silica	156	A yellowish white loose powder.
20 Lime 80 Silica	156	Not melted, formed a brittle mass.

Magnesia,

Equal parts of magnesia and silica melt with great difficulty into a white enamel when exposed to the most violent heat which can be produced ‡. They are infusible in inferior heats in whatever proportion they are mixed §.

And alumina.

There is a strong affinity between alumina and silica. When equal portions of silicated and aluminated

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* Gadolin, *Ann. de Chim.* xxii. 110.—Morveau Ibid. xxxi. 250.

† Kirwan's *Min.* i. 56.

‡ Lavoisier, *Mem. Par.* 1787, p. 598.

§ Achard, *Mem. Berl.* 1780, p. 33.

potass are mixed together, a brown zone immediately appears, which may be made, by agitation, to pass through the whole liquid. After standing about an hour, the mixture assumes the consistence of jelly[*]. When formed into a paste with water, and dried, they cohere, and contract a considerable degree of hardness. When baked in the temperature of 160° Wedgewood, they become very hard, but do not fuse[†]. Achard found them infusible in all proportions in a heat probably little inferior to 150° Wedgewood. But when exposed to a very strong heat, they are converted into a kind of opaque glass, or rather enamel. Porcelain, stoneware, brick, tiles, and other similar substances, are composed chiefly of this compound. Mixtures of silica and alumina in various proportions constitute *clays;* but these are seldom uncontaminated with some other ingredients.

It follows from the experiments of Achard, that equal parts of lime, magnesia, and silica, may be melted into a greenish coloured glass, hard enough to strike fire with steel; that when the magnesia exceeds either of the other two, the mixture will not melt; that when the silica exceeds, the mixture seldom melts, only indeed with him in the following proportions; three silica, two lime, one magnesia, which formed a porcelain; and that when the lime exceeds, the mixture is generally fusible[‡].

A mixture of silica and alumina may also be combined with barytes or strontian by means of heat. The mixture melts readily into a greenish coloured porcelain[§].

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[*] Morveau, *Ann. de Chim.* xxxi. 249.

[†] Kirwan's *Min.* i. 58.

[‡] *Mem. Berl.* 1780, p. 33. and *Jour. de Phys.* xxiv.

[§] Kirwan.

From the experiments of Achard and Kirwan, we learn that, in mixtures of lime, silica, and alumina, when the lime exceeds, the mixture is generally fusible either into a glass or a porcelain, according to the proportions. The only infusible proportions were,

2	3	Lime
1	1	Silica
2	2	Alumina.

That if the silica exceeds, the mixture is frequently fusible into an enamel or porcelain, and perhaps a glass; and that when the alumina exceeds, a porcelain may often be attained, but not a glass*.

As to mixtures of magnesia, silica, and alumina, when the magnesia exceeds, no fusion takes place at 150°. When the silica exceeds, a porcelain may often be attained; and three parts silica, two magnesia, and one alumina form a glass. When the alumina exceeds, nothing more than a porcelain can be produced†.

Achard found that equal parts of lime, magnesia, silica, and alumina, melted into a glass. They fused also in various other proportions, especially when the silica predominated.

Silica differs from all the other earths in not combining with any of the acids except the fluoric, phosphoric, and boracic; to which perhaps we may add the muriatic.

Silica is one of the most important of the earths. It is the chief ingredient of those stones which seem to constitute the basis of this terrestrial globe. It is an essential ingredient in mortar, in all kinds of stoneware, and in glass.

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* Kirwan's *Min.* i. 73.

† Ibid. i. 72.

SECT. X.

REMARKS ON ALKALIES AND EARTHS.

Fixed alkalies and earths

THE fixed alkalies and earths, taken in the order in which they have been described in the preceding Sections, constitute a regular series. The difference between the properties of potass and silica, which occupy the two extremities of this series, is very considerable; but the difference between the properties of any two contiguous bodies in the series is but small. Barytes, for instance, agrees with the fixed alkalies in so many particulars, that it might, without any impropriety, be arranged under the head of alkalies; and this has actually been done by Fourcroy. The same remark applies to strontian. These two bodies agree with lime also so nearly that they have been arranged with it by almost all chemists. Again, if we compare lime and magnesia, we shall find them to correspond in the greater number of their properties. In like manner, magnesia corresponds with alumnia; and the difference between alumnia, yttria, and glucina, is but small; yttra and glucina differ but little from zircona, while the correspondence between this last earth and silica is no less striking.

Belong to one class.

Perhaps, therefore, in strict propriety, the fixed alkalies and earths ought to be comprehended together in one general class: but the division of them into alkalies and earths was made at an early period, before the properties of the bodies comprehended under them had been examined; and this division has been still retained, though it is no easy matter to say what particular bodies ought to be arranged under each of these heads. Luckily the point is not of much consequence. The common division has been followed in the two preceding chapters. But some modern chemists, especially Fourcroy, have placed barytes and strontian among the alkalies. No fault can be found with this arrangement, because the division of these bodies into earths and alkalies is perfectly arbitrary. But surely if barytes and strontian be placed among alkalies, lime ought not to be excluded; for barytes and strontian do not possess a single alkaline property of which lime is destitute. And if lime be reckoned among the alkalies, no good reason can be given why magnesia should be excluded. The truth is, that these bodies graduate into each other so nicely that they can scarcely be placed in different classes. This is a sufficient reason for preferring the common division to the new one proposed by Fourcroy.

Difference between earths and alkalies.

When only potass, soda, and ammonia, are reckoned alkalies, and all the other bodies are considered as earths, the alkalies and earths may be distinguished from each other with precision; but this cannot be done if barytes and strontian be placed among the alkalies.

The essential properties of the alkalies are the following.

1. May be volatilized.

2. Soluble in alcohol.

3. Compounds which they form with carbonic acid and with oils, soluble in water.

The essential properties of the earths are the following.

1. Perfectly fixed.

2. Insoluble in alcohol *.

3. Compounds which they form with carbonic acid and with oils, insoluble in water.

Earths may be divided into *alkaline* and *proper*.

The earths may very properly be subdivided into two subordinate genera: namely, *alkaline earths* and *earths proper*. The alkaline earths are barytes, strontian, and lime. They agree with alkalies in taste, causticity, solubility in water, and in their effect on vegetable colours. The earths proper are, alumina, yttria, glucina, zirconia, and silica. They are tasteless, insoluble in water, and have no effect on vegetable colours. Magnesia is the link which unites these two genera together, partaking equally of the properties of both. Like the alkaline earths, it tinges vegetable blues green; and, like the earths proper, it is tasteless and insoluble in water.

Characteristics of the earths.

Some of the characteristic properties of the different earths are exhibited in the following TABLE †.

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[*] This must be understood within certain limits; for, according to Fourcroy and Vauquelin, alcohol dissolves a notable proportion of newly prepared barytes. See *Mem. de l'Institute*, ii. 61.

[†] In this Table several properties have been placed, with which the reader will become acquainted by perusing the subsequent part of this work. It was thought worth while to add them, that the Table might contain the most important properties of the earths collected together.

Earths.	Solubility in 1 of water.	Tinge vegetable blues green.	Soluble in potass.	Soluble in carbonat of ditto.	Soluble in carbonat of ammonia.	Soluble in muriatic acid *.	Precipitated by Prussiat of potass.	Precipitated by tan.	Precipitated by hydrosulphurets.	Precipitated by succinats.
Barytes	0.050	1				1				1
Stront.	0.005	2				2				2
Lime	0.002	3				3				3
Magnes.	0.000	4				4				
Alum.	0.000		1			5			1	
Yttria	0.000			1	1	6	1	1		
Glucina	0.000		2	2	2	7		2		4
Zircon.	0.000			3		8	2	3	2	
Silica	0.000		3							

It deserves attention, that a considerable number of these bodies may be divided into pairs, which have a striking resemblance to each other. These pairs are,

1. { Potass, Soda
2. { Barytes, Strontian
3. { Yttria, Glucina
4. { Alumina, Zirconia

But the resemblance between alumina and zirconia, which constitute the last pair, is not so close as that between the bodies which form the other pairs. Am-

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* After being precipitated.

monia, magnesia, and silica, have none of them corresponding substances.

All the alkalies and earths combine with acids, except silica. None of them are combustible, if we except ammonia, and it is not combustible unless it be decomposed; of course none of them are capable of combining with oxygen. Neither do any of them combine with carbon, hydrogen, or azote. The alkalies and alkaline earths combine with sulphur; alkaline earths only combine with phosphorus: neither alkalies nor earths combine with metals; but they have an affinity for several of the metallic oxides.

Of their component parts.

As none of the earths have been hitherto decompounded, we must, in the present state of chemistry, consider them as simple bodies. Many attempts, indeed, have been made to shew that there was but one earth in nature, and that all others were derived from it. The earth generally made choice of as the simplest was silica *. But none of these attempts, notwithstanding the ingenuity of several of the authors, has been attended with the smallest shadow of success.

Some time ago an attempt was made to prove that all the earths are metallic oxides, and that they can actually be reduced to the state of metals.

Baron had long ago suspected that alumina had somewhat of a metallic nature; and Bergman had been induced, by the great weight of barytes, and several other appearances, to conjecture that it was a metallic oxide: But the first chemist who ventured to hint that all earths might be metallic oxides was Mr Lavoisier †.

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* Mr Sage, however, pitched upon lime.

† *Chemistry*, p. 217. English Transl.

About the year 1790, soon after the publication of Mr Lavoisier's book, Mr Tondi and professor Ruprecht, both of Schemnitz, announced, that they had obtained from barytes, by the application of a strong heat, a metal of the colour of iron, and attracted by the magnet, which they called *borbonium ;* from magnesia another, which they called *austrum ;* a third from lime, also called *austrum ;* and a fourth from alumina, which they denominated *apulum*. Their method of proceeding was to apply a violent heat to the earths, which were surrounded with charcoal in a Hessian crucible, and covered with calcined bones in powder.

But their experiments were soon after repeated by Klaproth, Savoresi, and Tihauski ; and these accurate chemists soon proved, that the pretended metals were all of them *phosphurets of iron*. The iron, by the violence of the heat, had been extracted from the crucible, and the phosphorus from the bones. The earths therefore must still continue a distinct class of bodies : and, as Klaproth has observed, the properties of most of them are so exceedingly different from those of metallic oxides, that the supposition of their being composed of the same ingredients is contrary to every fact, and to every analogy with which we are acquainted. Some of the earths indeed agree with metallic oxides in some of those properties which are considered as peculiarly characteristic, and seem therefore to constitute the link which unites the earths with the oxides *. This is the case in particular with yttria and zirconia. But the

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* The properties alluded to are, forming coloured salts with acids, being precipitated by prussic alkali, and by an infusion of nut-galls.

Book II. Division I.

reason of this coincidence must remain a secret, till the component parts of the earths be ascertained. It is to be hoped that this important point will not remain much longer a desideratum in chemistry. Desormes and Morveau had announced that they considered potass as composed of lime and hydrogen, and soda of magnesia and hydrogen. From other experiments, they were led to infer, that lime is composed of carbon, azote, and hydrogen; and magnesia of lime and azote *. But the experiments of Darracq have demonstrated, that the results obtained by these chemists were owing to the impurity of the substances on which they operated †.

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* *Mem. de l'Instit.* iii. 321.

† *Ann. de Chim.* xl. 171.

CHAP. III.

OF OXIDES.

We have now given an account of all the known substances which chemists have not hitherto been able to decompound, excepting only one, namely, *fluoric acid*; the properties of which will be considered afterwards. Of these simple substances, the most remarkable is *oxygen*. It is capable of combining with all the rest except the inconfinable bodies, the fixed alkalies, and the earths. We have seen, too, that it combines with bodies usually in various proportions, constituting a variety of compounds with almost every substance with which it is capable of uniting. Now the whole of the compounds into which oxygen enters, may be divided into two sets: 1. Those which possess the properties of *acids*; and, 2. Those which are destitute of these properties. The first set of compounds are distinguished by the term *acids*; to the second, the term *oxide* has been appropriated. By *oxide*, then, is meant a substance composed of oxygen and some other body, and destitute of the properties which belong to acids. In this and the following chapter we shall consider the properties of these two sets of compounds. It is by no means uncommon to find a compound of the same base

Combinations of oxygen.

and oxygen belonging to both of these sets, according to the proportion of oxygen which enters into the compound. In all these cases, the smaller proportion of oxygen constitutes the *oxide*; the larger the *acid*. Hence it follows, that oxides always contain less oxygen than acids with the same base. We shall therefore consider the oxides, in the first place, in this chapter, and reserve the examination of the acids for the next.

Different species of oxides.

1. Oxygen combines with three distinct set of bodies, the simple combustibles, the incombustibles, and the metals, and forms oxides with every individual belonging to these sets. These oxides vary according to the substance which constitutes the base; but all the oxides of the simple combustibles are *combustible*, except the oxide of hydrogen, which is a *product* of combustion; all the oxides of the simple incombustibles are supporters of combustion; and all the oxides of the metals are either products of combustion or supporters. Of course, the first set of oxides (except that of hydrogen) cannot be formed by combustion; neither can the second set; but part of the third set are formed by combustion, a part by the union of the oxygen of supporters without combustion.

2. Besides these oxides, which may be considered as simple, because they contain but one ingredient combined with oxygen, there is another set much more numerous than they, consisting of oxygen united at once with two or more simple substances. These bodies may be distinguished from the others by giving them the name of *compound oxides*. The consideration of these last must be referred to another head, as they do not usually go under the name of oxides.

3. We ought now to proceed to consider the pro-

Chap. III.

perties of the primary oxides, according to the division laid down above. But, upon mature reflection, it will be found that the science of chemistry is scarcely far enough advanced to permit us to follow that method. The oxides of sulphur and phosphorus have been examined so superficially, that we thought it better to point out the few facts known concerning them, when speaking of sulphur and phosphorus, than to give them separately. For the same reason we gave an account of the metallic oxides while treating of the metals. The only oxides, therefore, which remain for our investigation, are those of the two simple combustibles, carbon and hydrogen; and those of azote: for the compounds which muriatic acid forms with oxygen have been considered as *acids*. These oxides shall occupy our attention in the following Sections.

SECT. I.

OF THE OXIDES OF CARBON.

We have seen formerly that carbon is capable of uniting with three different doses of oxygen, and of forming two oxides and one acid. The oxides are *carbonous oxide* or charcoal, which contains the smallest proportion of oxygen; and *carbonic oxide*, which contains a larger proportion.

I. OF CHARCOAL.

WE have already, while treating of carbon, given the method of preparing charcoal, and detailed a number of its properties; but it will be necessary to resume the subject, and to treat it, if possible, with more precision, because it constitutes one of the most obscure and difficult parts of chemistry. I prefer the word *charcoal* to *carbonous* oxide, that we may be at liberty to take a more general view of the subject.

Two species of charcoal, common

1. When charcoal is prepared in the usual way, by exposing wood in close vessels to a red heat, it always contains a portion of hydrogen: For if a quantity of this charcoal be exposed to a strong heat in a retort of porcelain, iron, or coated glass, a great quantity of gas is obtained. The gas which comes over first is a mixture of carbonic acid and carbureted hydrogen; but the proportion of carbonic acid diminishes, and at last it ceases to come over at all; yet the carbureted hydrogen continues as copious as ever *.

The evolution of these gases was long ascribed by chemists to the water which charcoal usually contains, and which it is known to absorb from the atmosphere with considerable avidity. If that were the case, the proportion of carbureted hydrogen ought to diminish at the same rate with the carbonic acid; the hydrogen of the one being equally derived from the decomposition of water with the oxygen of the other. But as the evolution of carbureted hydrogen continues after

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* Cruikshank, Nicholson's *Journal*, 1802. v. 210.

that of carbonic acid has ceased, it is scarcely possible to deny, that the hydrogen which thus escapes constituted a component part of the charcoal.

If, therefore, we consider the experiments of Morveau on the combustion of the diamond as decisive, we must conclude, that common charcoal is composed of three ingredients, namely, carbon, hydrogen, and oxygen. It is of course a triple compound. This is the opinion at present generally entertained by chemists: even Mr Berthollet himself, though sceptical with regard to many of the combinations of carbon, admits the truth of this opinion.

And prepared.

2. When common charcoal is exposed for an hour in a close crucible to the strongest heat of a forge, it ceases to emit gas; and no temperature is sufficient to expel gas from charcoal thus treated *. Desormes and Clement have endeavoured to demonstrate, that by this treatment common charcoal is deprived of the whole of its hydrogen. They put a quantity of charcoal, recently exposed to the heat of a forge, and not yet cold, into the middle part of a long glass tube. To each extremity of the tube was fixed another tube, filled with dry *muriat of lime*, and surrounded with a mixture of snow and salt. To the extremity of one of these tubes was fixed an empty bladder; to the extremity of the other, a bladder containing a quantity of oxygen gas. The charcoal was heated to redness by placing the tube in a furnace, and then the oxygen gas was made to pass slowly over it from one bladder to the other. By this contrivance the charcoal was burnt, and con-

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* Desormes and Clement, *Ann. de Chim.* xxxix. 29.

Book II. Division I.

verted into carbonic acid. The oxygen gas, in passing through the muriat of lime, was made to deposite the moisture which it contained, and the proportion was known by the increase of weight of the muriat. If the charcoal contained hydrogen, water would be formed during its combustion, which would unite with the carbonic acid formed. But this gas would deposite its moisture, during its passage through the muriat of lime at the other extremity of the tube, and the increase of weight which this muriat would experience would indicate the proportion of water formed during the process. In both cases, the muriat of lime was increased in weight 0.02 parts. Were we to suppose this increase owing to the formation of water, the small quantity would only contain hydrogen to the amount of $\frac{1}{1500}$ of the charcoal ; a portion too small to be regarded *.

The same chemists tried the combustion of charcoal obtained from a variety of other substances exposed to the heat of a forge, as pitcoal, animal substances, and various vegetable substances, and found the products exactly the same. Hence they conclude that charcoal is in all cases the same, provided it be exposed to a strong enough heat. And they conclude, too, that by this strong heat the whole hydrogen of common charcoal is expelled.

But this is going rather farther than their experiments will warrant ; and it is directly contrary to the experiments of Cruikshank, who always found gases, obtained by means of charcoal in whatever state, to contain hydrogen. Besides, Berthollet has pointed out circum-

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* *Ann. de Chim.* xlii. 128.

stances which render the precision of these chemists somewhat doubtful.

Both contain some hydrogen.

3. Such are the facts at present known respecting the composition of charcoal. They enable us to conclude, that there are two species of charcoal, namely, *common* and *prepared charcoal*. The first contains three ingredients; carbon, hydrogen, and oxygen; the second is deprived of a portion of its hydrogen and oxygen. It consists chiefly of carbon and oxygen united; but it still retains a small portion of hydrogen, and is not, therefore, strictly speaking, a pure oxide of carbon, though it approaches very nearly to such an oxide.

II. OF CARBONIC OXIDE.

History.

THE substance at present known by the name of *carbonic oxide*, is a gas which had been confounded with carbureted hydrogen, till Dr Priestley drew the attention of chemists to it in a dissertation which he published in defence of the doctrine of phlogiston. His experiments were immediately repeated, and his opinions confirmed by Dr Woodhouse of Pennsylvania. But the real nature and composition of the gas was discovered by Mr Cruikshank of Woolwich, and the discovery communicated to the public in 1802 *. About the time of the publication of Mr Cruikshank's dissertation, the experiment of Woodhouse, which he had transmitted to France, engaged the attention of the National Institute. Guyton Morveau, who had been appointed to give a detailed account of these experi-

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* Nicholson's *Journal*, v. 1. and 201.

ments, engaged Clement and Desormes to investigate the subject; and these gentlemen were gradually led to the same conclusions[*] which had been previously drawn by Cruikshank. The subject, in the mean time, attracted the attention of Berthollet, whose experiments induced him to form a different opinion respecting the composition of charcoal and carbonic oxide from that which had been entertained by the other chemists. This opinion he supported in three elaborate dissertations, published in the fourth volume of the Memoirs of the National Institute; in which he examines the experiments, and combats the conclusions of the other chemists with his usual segacity. About the same time a dissertation was published by the Dutch chemists, contradicting the experiments of all other philosophers, and affirming the real results to be very different[†]. This short historical sketch is a sufficient proof of the great difficulty attending the investigation. No less than four different opinions have been maintained, and every one of them by men of eminence, of acknowledged skill, and undoubted candour.

Preparation.

1. There are four different processes by which carbonic oxide gas may be procured. *First*, When a mixture of purified charcoal and the oxides of iron or zinc, or indeed of any oxide capable of bearing a red heat, is exposed to a strong heat in an iron retort, the oxide is gradually reduced, and during the reduction a great quantity of gas is evolved. This gas is a mixture of carbonic acid gas and another which burns with a blue flame. It is to this last that the term *carbonic oxide* has been applied.

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[*] *Ann. de Chim.* xxxix. 88. and xlii. 121.

[†] Ibid. xliii. 113

The carbonic acid may be separated by passing the gas through lime water. Mr Cruikshank tried in this way the oxides of iron, zinc and copper, litharge, and the black oxide of manganese. The following conclusions result from his experiments. Those oxides which part with their oxygen most readily yield the greatest proportion of carbonic acid; those that retain their oxygen most obstinately yield the greatest proportion of carbonic oxide. It is always towards the beginning of the process that the greatest proportion of carbonic acid gas comes over; it gradually diminishes, and at last nothing but carbonic oxide is disengaged *. The results obtained by Clement and Desormes coincide almost exactly with the experiments of Cruikshank. But they satisfied themselves with the white oxide of zinc, without trying those of other metals. They substituted plumbago for charcoal, and obtained the same results †.

Second, When a mixture of one part of purified charcoal and three parts of the carbonat of lime, or of strontian, or of barytes, is exposed to a strong heat in an iron retort, the carbonic acid is gradually separated or decomposed, and gas is evolved in abundance. This gas consists of a mixture of about one part of carbonic acid to five parts of carbonic oxide ‡. In this case, a portion of the carbonic acid of the carbonat is disengaged unaltered, but the greatest part of it is converted into carbonic oxide by the action of the charcoal.

Third, When a mixture of equal parts of any of the three above-mentioned earthy carbonats and clean iron

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* Nicholson's *Journal*, 1802, v. ii.

† *Ann. de Chim.* xxxix. 33.

‡ Clement and Desormes. *Ibid.* 45.

filings is heated strongly in an iron retort, the carbonic acid is decomposed in like manner by the action of the iron, and the very same gases are procured in great abundance. Dr Priestley first tried this method with the black oxide of iron and carbonat of barytes; but when Cruikshank substituted pure iron, the gaseous product was considerably increased *.

Fourth, When carbonic acid gas is made to pass slowly and repeatedly through prepared charcoal heated to redness in a porcelain or iron tube, it gradually disappears, and carbonic oxide is found in place of it. Here the charcoal decomposes the carbonic acid precisely as in the two last cases, with this difference only, that it is in a gaseous state, whereas in them it was combined with a base. This experiment was first made by Cruikshank †, and afterwards by Clement and Desormes ‡.

How purified.

2. Such are the different processes for procuring carbonic oxide. From the experiments of Cruikshank we learn, that the third method is the only one to be depended on for obtaining the gas in a state of purity. If equal parts of chalk and iron filings, previously exposed to a red heat separately in close vessels, be mixed together and strongly heated in an iron retort, the gases which come over are merely a mixture of carbonic acid and carbonic oxide; and the first being abstracted by means of lime water, the carbonic oxide gas remains in a state of purity.

Properties.

3. Carbonic oxide gas, thus obtained, is invisible and elastic like common air. Its specific gravity, according to the experiments of Cruikshank, is 0 001167, or it

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* Nicholson's *Journal*, 1802, v. 4. and 208.

† Ibid. p. 209.

‡ *Ann. de Chim.* xxxix 46.

is to common air as 22 to 23. One hundred cubic inches of it, therefore, weigh 30 grains. The result obtained by Desormes and Clement does not differ much from this*.

Animals cannot breathe this gas without suffocation. Birds put into it by Desormes and Clement dropt down dead before they had time to take them out; and when they attempted to breathe it themselves, the consequence was giddiness and faintness†. Neither will any combustible body burn in it.

It is not altered by exposure to light, nor by passing it through a red hot tube. From the experiments of Clement and Desormes, we find that it is dilated by heat exactly like common air, as was indeed to be expected.

Combustible.

4. Carbonic oxide gas is combustible. It takes fire in the open air when it comes in contact with a red hot body, or when it is presented to the flame of a candle, and burns with a lambent blue flame. When mixed with common air before it is kindled, it burns more rapidly and brilliantly, but does not detonate. The combustion is still more rapid and brilliant if we substitute oxygen gas for common air. But neither in this case does detonation take place‡.

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* By taking a mean of their experiments, we obtain the weight of a litre of gas 1.135 grammes, which reduced to our standard gives the weight of 100 cubic inches 28.7 grains. Their result would have been still nearer Cruikshank's, had I excluded their trials with some of the lightest and impurest gases which they obtained.

† *Ann. de Chim.* xxxix. 56.

‡ The French chemists speak of the detonation of this gas with oxygen. They must refer to a kind of whistling noise which is heard at the instant of combustion, very different from detonation in the usual acceptation of the wod.

From the experiments of Cruickshank, which have been confirmed by those of Clement and Desormes, we learn that 100 cubic inches of carbonic oxide, in order to undergo complete decomposition, must be mixed before combustion with 40 cubic inches of oxygen gas; and this mixture, being exploded by electricity in a detonating tube, is converted into 92 cubic inches of carbonic acid gas. Or, in numbers, 30 grains of carbonic oxide require for saturation about 13.3 grains of oxygen; and the resulting compound amounts to 43.3 grains of carbonic acid gas. No sensible quantity of water is formed by the combustion of this gas when it is procured by the third process, and made as dry and pure as possible before the experiment.

Action of simple combustibles.

5. This gas has no action whatever upon the simple combustibles at the common temperature of the atmosphere; but its activity is somewhat augmented by the assistance of heat.

When passed through melted sulphur, it does not combine with it, nor alter its properties; but it dissolves a little phosphorus, and acquires the property of burning with a yellow flame. When passed through red hot charcoal, it dissolves a part of it, if we believe Desormes and Clement, and its specific gravity is increased. The same chemists affirmed, that when a mixture of carbonic oxide and hydrogen gas is made to pass through a red hot glass tube, charcoal is deposited, which lines the inside of the tube with a shining enamel; that water is formed, and hydrogen, seemingly pure, disengaged from the other end of the tube*. But

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* *Ann. de Chim.* xxxix. 61.

when this experiment was repeated by Saussure junior, he found that the supposed enamel of charcoal was merely the black (or rather bluish) colour which flint glass acquires when hydrogen is brought in contact with it at a red heat, as had been previously observed by Dr Priestley †. Indeed it is very unlikely that hydrogen gas is capable of decomposing carbonic oxide; as Saussure has shewn, that when carbonic acid and hydrogen gas are made to pass through a red hot tube, the acid is decomposed and carbonic oxide produced—a result which has been even confirmed by the subsequent experiments of Clement and Desormes.

Of incombustibles.

6. Neither of the simple incombustibles produces any change upon carbonic oxide at any temperature hitherto tried; but the action of oxymuriatic acid gas upon it is extremely curious and important. For the investigation of this part of the subject we are entirely indebted to Mr Cruikshank, who has thereby disclosed to chemists a new and valuable method of trying the purity and composition of the combustible gases.

Of oxymuriatic acid.

If a phial be filled with a mixture of two measures of carbonic oxide gas and $2\frac{2}{3}$ measures of oxymuriatic acid gas †, then closed with a ground stopper, and allowed to remain for 24 hours with its mouth inverted under mercury, on drawing the stopper under water, two thirds of the gas are immediately absorbed, and all the rest by agitation in lime-water (except $\frac{1}{6}$ of a measure of azote) ‡. Hence we see that these two gases act upon

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* *Jour. de Phys.* lv. 396.

† Procured by pouring muriatic acid on the hyperoxymuriat of potass.

‡ Nicholson's *Journal*, 1802, v. p. 205.

each other at the temperature of the atmosphere; that the carbonic oxide gradually abstracts oxygen from the other gas, and is converted into carbonic acid. The oxymuriatic acid gas thus decomposed is converted into muriatic acid, which is instantly absorbed on the admission of water. Thus by the mutual action of the two gases, the whole is converted into carbonic acid and muriatic acid.

Mr Cruikshank ascertained, that this mixture of carbonic oxide and oxymuriatic acid gas does not burn when electric sparks are made to pass through it, nor is its nature altered; whereas a mixture of carbureted hydrogen and oxymuriatic acid gas explodes immediately. This difference enables us to distinguish carbureted hydrogen from carbonic oxide with the greatest facility*.

Of metals,

7. From any experiments hitherto made, it does not appear that carbonic oxide is capable of acting on the metals; but Clement and Desormes affirm, that when passed hot over the red oxide of mercury, it produces a commencement of reduction. Indeed it is very likely that it will be found capable of reducing several of the metallic oxides, especially those that part with their oxygen easily.

Alkalies, and earths.

8 Neither the fixed alkalies nor the earths have any action on carbonic oxide. Neither does ammonia alter it when passed with it in the state of gas through a red hot tube†.

Composition.

9. From the history of the properties of this gas just given, it must be obvious at once, that it contains car-

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* Nicholson's *Journal*, 1802, v. p. 207

† Clement and Desormes, *Ann. de Chim.* xxxix. 61.

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bon as an ingredient; for when fired with oxygen, it yields carbonic acid gas as a product. That it differs from carbureted hydrogen is obvious from its specific gravity, from the action of oxymuriatic acid gas, and from the result obtained by burning it. As it yields on combustion no perceptible portion of water, it was concluded by Cruikshank, and afterwards by Guyton-Morveau, Desormes and Clement, that it contained no hydrogen, and contained no other combustible base besides *carbon*. But it requires much less oxygen gas for combustion than charcoal. Thus 100 parts of charcoal require 257 parts of oxygen to saturate them; whereas 100 parts of carbonic oxide require only 45$\frac{1}{3}$ parts of oxygen; and in both cases carbonic acid is produced. This remarkable difference can only be accounted for by supposing that the carbonic oxide is already combined with a portion of oxygen, and therefore a smaller addition must be sufficient to saturate it. Accordingly this was the consequence drawn by Cruikshank; and it is impossible to resist the evidence in favour of his conclusions. The gas therefore, according to this reasoning, is a compound of carbon and oxygen. Hence the name *carbonic oxide* given to it by chemists.

On the supposition that the experiments of Morveau on the diamond are precise, and that prepared charcoal is an oxide of charcoal composed of the proportions stated in a former part of this Work, it will be easy for us to ascertain, from the experiments of Cruikshank, the component parts of this oxide.

Mr Cruikshank found that 30 grains of carbonic oxide combine by combustion with about 13.6 grains of oxygen, and the carbonic acid formed amounts to about 43.6 grains. Hence it follows that carbonic acid is

composed of 69 carbonic oxide
31 oxygen
———
100

But 100 parts of carbonic acid are composed of 18 carbon and 82 oxygen. Consequently

Carbon. Oxygen. Carbonic Oxide.
$18 + 82 = 69 + 31$ oxygen,

From which it follows that 69 carbonic oxide is composed of 18 carbon and 51 oxygen.

Therefore carbonic oxide contains 26 carbon
74 oxygen
———
100

Charcoal is composed of 64.3 carbon
35.7 oxygen
———
100.0

Therefore 26 parts of carbon, in order to form charcoal, must combine with 14 parts of oxygen; consequently carbonic oxide is composed of 40 charcoal
60 oxygen
———
100

Hence it follows that carbon combined with one dose of oxygen constitutes charcoal; combined with two doses it constitutes carbonic oxide; combined with three doses it constitutes carbonic acid. Thus

Carbon. Oxyg. Charcoal.
$100 + .56 = 1.56$
Oxyg. Carb. Oxide.
$1.56 + 2.27 = 3.83$
Oxyg. Carb. Acid.
$3.83 + 1.72 = 5.55$

Theory of Berthollet.

But all this statement has been called in question by Berthollet. According to this sagacious philosopher, there are two different species of inflammable gases containing carbon. The first species is composed of carbon and hydrogen; the second, of carbon, hydrogen, and oxygen. To distinguish these two species from each other, he calls the first *carbureted hydrogen*; the second, *oxycarbureted hydrogen*. To the first species belong the gases obtained by passing alcohol through a red hot tube, by distilling oil, and by exposing moist charcoal to a red heat, &c. To the second species belong the gas produced by exposing charcoal to a strong heat, the gas obtained by distilling sugar, the gas described in this Section under the name of carbonic oxide, &c. There are many varieties of these gases, differing from each other in the proportions of their ingredients; and the gases belonging to the first species may, by various processes, be converted into the second. He calculates the proportion of hydrogen in carbonic oxide to be about $\frac{1}{25}$ of the whole.

These conclusions are obviously irreconcileable with the experiments of Cruikshank and of Desormes and Clement, and cannot therefore be admitted without very decisive proofs. The carbonic oxide obtained by Cruikshank, when as pure as possible, yielded no perceptible quantity of water when burnt with oxygen. But Berthollet observes that all gases contain water as a constituent part, and shews that all the water that could have been formed would have combined with the carbonic acid gas, and remained invisible. Even if we were to grant this, and to allow that some water has been formed in every case of the combustion of carbonic oxide with oxygen hitherto tried, still Berthollet's hypothesis would stand upon as [illegible] ground as ever. For it is obvious from the experiments of Cruik-

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shank, that the drier he made his materials the purer was the gas, or the less water was formed during its combustion; and when he employed bodies that could not contain any hydrogen except in the state of water (namely, dry chalk and tin or iron), the gas was obtained purest of all.

Mr Berthollet's chief reason for affirming that carbonic oxide must contain hydrogen is its small specific gravity. The specific gravity of

oxygen gas is	0.00135
carbonic oxide	0 00116
carbonic acid	0.00180

The specific gravity of carbon is undoubtedly much greater than any of the three. Now when oxygen gas combines with carbon, and forms carbonic acid, its specific gravity is increased, as happens in other cases. But how is it possible, says Berthollet, to conceive that the addition of carbon should diminish the specific gravity of oxygen gas, as would be the case if carbonic oxide were composed of these two ingredients only? Nay, carbonic acid, by dissolving an additional dose of carbon, would not only become specifically lighter than before, but even specifically lighter than oxygen gas, which Berthollet considers as incredible. But this reasoning is by no means sufficient to induce us to refuse credit to the conclusions of Cruikshank; for similar instances are by no means so uncommon as Berthollet supposes. Mr Chenevix has shewn that mercury, the specific gravity of which is 13.5, when combined with platinum of the specific gravity 21 (at least), acquires a specific gravity of only 11.5. An instance still more in point has been mentioned by Mr Davy*. The spe-

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* *Journals of the Royal Institution*, i. 317.

cific gravity of oxygen gas is 0.00135
azotic gas 0.00115
nitrous oxide 0.00197
nitric oxide 0.00134

Now when nitric oxide is converted into nitrous oxide by abstracting a portion of its oxygen, the heaviest of its component parts, its specific gravity is increased. This is as great an anomaly as that at which Mr Berthollet startles.

SECT. II.

OF WATER.

Hydrogen differs from all the other combustible bodies in being capable of combining with only one dose of oxygen, and forming with it a compound entirely destitute of acid properties, and which therefore must be ranked among the oxides. This compound is *water.*

This well-known liquid is found in abundance in every part of the world, and is absolutely necessary for the existence of animals and vegetables. When pure, in which state it can be obtained only by distillation, it is transparent, and destitute of colour, taste, and smell.

Weight.

1. As this liquid, from the ease with which it may be procured in a state of purity, has been chosen for a standard by which the comparative weight of all other bodies may be estimated, it becomes of the greatest importance to ascertain its weight with precision: But its density varies with the temperature. At the tempera-

ture of $42\frac{1}{2}°$, its density is a maximum; and for the two or three degrees on each side of $42\frac{1}{2}°$, the variation of its density is scarcely perceptible. Now, from the experiments of Lefevre Gineau, performed with great care, in order to ascertain the weight of the millegramme, it follows, that, at the temperature of 40°, a French cubic foot of distilled water weighs 70 lbs. and 223 grains French = 529452.9492 grains troy*. Therefore an English cubic foot, at the same temperature, weighs 437102.4946 grains troy, or 999.0914161 ounces avoirdupois. A cubic foot of water, at the temperature of 55°, weighs, according to the experiments of Professor Robison of Edinburgh, 998.74 avoirdupois ounces, of 437.5 grains troy each, or only 1.26 ounces less than 1000 avoirdupois ounces: so that rain water, at the same temperature, will weigh pretty nearly 1000 ounces. The specific gravity of water is always supposed = 1.000, and it is made the measure of the specific gravity of every other body.

Ice.

2. When water is cooled down to 32°, it assumes the form of ice. If this process goes on very slowly, the ice assumes the form of crystalline needles, crossing each other at angles either of 60° or 120°, as Mr de Mairan has remarked; and it has been often observed in large crystals of determinate figures. Ice, while kept at a temperature considerably below 32°, is very hard, and may be pounded into the finest dust. It is elastic. Its specific gravity is less than that of water.

Steam.

3. When water is heated to the temperature of 212°, it boils, and is gradually converted into steam. Steam

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* *Jour. de Phys.* xlix. 171.

is an invisible fluid like air, but of a less specific gravity. It occupies about 1800 times the space that water does. Its elasticity is so great, that it produces the most violent explosions when confined. It is upon this principle that the steam-engine has been constructed.

Boiling point affected by salts.

The phenomena of boiling are owing entirely to the rapid formation of steam at the bottom of the vessel. The boiling point of water varies according to the pressure of the atmosphere. In a vacuum water boils at 70°; and when water is confined in Papin's digester, it may be almost heated red hot without boiling. The mixture of various salts with water affect its boiling point considerably. Mr Achard made a number of experiments on that subject; the result of which may be seen in the following Tables*.

Class I. *Salts which do not affect the Boiling Point.*

Sulphat of copper.

Class II. *Salts which raise the Boiling Point.*

A saturated solution of	Raises the boiling point
Muriat of soda	10.35°
Sulphat of soda	5.6
Sulphat of potass	0 9
Nitrat of potass	3.5
Boracic acid	2.2
Carbonat of soda	2.35

This augmentation varies with the quantity of salt dissolved. In general, it is the greater the nearer the solution approaches to saturation.

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* *Trans. Berlin*, 1785.

CLASS III. *Salts which lower the Boiling Point.*

Borax,	In a small quantity, lowers the boiling point	1.350°
	Saturated solution of	0.22
Sulphat of magnesia,	In a small quantity	2.47
	Saturated solution of	1.1
Alum,	A very small quantity of	0.0
	A greater quantity	0.7
	A saturated solution of	0.0
Sulphat of lime,	in any proportion,	2.02
Sulphat of zinc,		0.45
Sulphat of iron,		0.22
Acetite of lead,		1.24

CLASS IV.

Muriat of ammonia,	Small quantity of, lowers the boiling point	0.45°
	Saturated solution of, raises do.	9.79
Carbonat of potass,	Small quantity of, lowers do.	0.45
	Saturated solution of, raises do.	11.2

Water was once supposed to be incompressible; but the contrary has been demonstrated by Mr Canton. The Abbé Mongez made a number of experiments, long after that philosopher, on the same subject, and obtained similar results.

Action of heat.

4. Water is not altered by being made to pass thro' a red hot tube. Heat does not seem capable of decomposing it; neither is it affected by the action of light.

Absorbs air.

5. It has the property of absorbing atmospheric air; and it always contains a portion of it when it has been exposed to the atmosphere. The greater part of this

air is driven off by boiling: but, from the experiments of Dr Priestley, it appears that the whole of it is not separated; nor can it be completely separated without great difficulty. Water owes its agreeable taste to the presence of air; hence the insipidity of boiled water. It absorbs oxygen gas in preference to air, and nearly in the same proportion, as was first ascertained by Scheele.

How air may be separated from it.

Mr Driessen has shewn, that, in order to free water from air, it must be boiled for at least two hours, and kept in a flask with its mouth inverted over mercury. If it be exposed to the air, after this process, for ever so short a time, it immediately absorbs some air; a proof of the strong affinity which it has for that fluid*. This philosopher has pointed out the following method of ascertaining whether water be perfectly free from air. Tinge the water blue with litmus, fill a flask with it, invert the flask under water, and introduce into it pure nitrous gas till about $\frac{1}{10}$ of the vessel is filled. If the water contain air, a portion of the nitrous gas will combine with its oxygen, and be converted into nitric acid. The consequence of which will be, that the litmus will assume a red colour. Even the proportion of air in the water may be estimated by the quantity of ammonia necessary to restore the blue colour to the litmus. If the litmus retains its blue colour, we may be certain that the water which we try contains no sensible portion of air†.

Action of the

6. Water has no action on any of the simple combustibles while cold; nor does it combine with any of

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* *Phil. Mag.* 1803, xv. 252.

† Ibid.

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Simple combustibles.

them. It is not altered by sulphur nor hydrogen even at a red heat; but it is decomposed by charcoal at that temperature. The action of phosphorus on it in a red heat has not been tried.

Of the metals,

7. Several of the metals are not altered by it; others decompose it, and are converted into oxides. But the action of metals on it has been already described.

Alkalies, and earths.

8. Water dissolves the alkalies and alkaline earths; the other earthy bodies are insoluble in it. It combines also with acids and with a vast number of substances: all bodies, indeed, which are soluble in water form a chemical union with it.

Affinity.

9. Its affinity for other bodies is doubtless various, though we have no method of ascertaining this difference, except in those bodies which have no affinity, or but a very small affinity for each other; and it is only in a few even of these that this difference can be ascertained. Oxide of azote, for instance, separates common air from water, and sulphureted hydrogen or carbonic acid gas separates oxide of azote. Hence we see that the affinities of these bodies for water are in the following order:

Carbonic acid gas,
Sulphureted hydrogen,
Oxide of azote,
Air.

10. All gases in their usual state contain combined with them a quantity of water, which often amounts to a considerable proportion of their weight. Part of this water may be abstracted by exposing the gases to substances which have a strong affinity for water, as dry potass; but part adheres with a great deal of obstinacy, and perhaps cannot be removed by any method in our power.

Opinions about the nature of water.

11. Water was believed by the ancients to be one of the four elements of which every other body is composed; and, according to Hippocrates, it was the substance which nourishes and supports plants and animals. That water was an unchangeable element continued to be believed till the time of Van Helmont, who made plants grow for a long time in pure water: from which experiment it was concluded, that water was convertible into all the substances found in vegetables. Mr Boyle having digested pure water in a glass vessel hermetically sealed for above a year, obtained a quantity of earthy scales; and concluded, in consequence, that he had converted it partly into earth [*]. He obtained the same earth by distilling water in a tall glass vessel over a slow fire [†]. Margraff repeated the experiment with the same result, and accordingly drew the same conclusion. But the opinion of these philosophers was never very generally received. The last person who embraced it was probably Mr Waselton, who published his experiments on the subject in the *Journal de Physique* for 1780. Mr Lavoisier had proved, as early as 1773, that the glass vessels in which the distillation was performed lost a weight exactly equal to the earth obtained. Hence it follows irresistibly, that the appearance of the earth, which was silica, proceeded from the decomposition of the vessels; for glass contains a large proportion of silica. It has been since shown by Dr Priestley, that water always decomposes glass when applied to its surface for a long time in a high temperature.

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[*] Shaw's *Boyle*, iii. 417.

[†] Ibid. i. 267.

History of the discovery of its component parts.

Water is now known to be an oxide of hydrogen, or a compound of oxygen and hydrogen. As this discovery has almost entirely altered the appearance of the science of chemistry, by furnishing an explanation of a vast number of phenomena which were formerly inexplicable; it will be worth while to give a particular account of the different steps which gradually led to it.

The first person probably who attempted to discover what was produced by burning hydrogen gas was Scheele. He concluded, that during the combustion oxygen and hydrogen combined, and that the product was caloric.

In 1776 Macquer, assisted by Sigaud de la Fond, set fire to a bottle full of hydrogen gas, and placed a saucer above the flame, in order to see whether any fuliginous smoke would be produced. The saucer remained perfectly clean; but it was moistened with drops of a clear liquid, which they found to be pure water*.

Next year Bucquet and Lavoisier exploded oxygen and hydrogen gas, and made an attempt to discover what was the product; about the nature of which they had formed different conjectures Bucquet had supposed that it would be carbonic acid gas; Lavoisier, on the contrary, suspected that it would be sulphuric or sulphurous acid. What the product was they did not discover; but they proved that no carbonic acid gas was formed, and consequently that Mr Bucquet's hypothesis was ill founded †.

In the beginning of the year 1781, Mr Warltire, at

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* Macquer's *Dictionary*, art. *Gas inflammable*.

† *Mem. Par.* 1781, p. 470.

the request of Dr Priestley, fired a mixture of these two gases contained in a copper vessel; and observed, that after the experiment the weight of the whole was diminished. Dr Priestley had previously, in the presence of Mr Warltire, performed the same experiment in a glass vessel. This vessel became moist in the inside, and was covered with a sooty substance*, which Dr Priestley afterwards supposed to be a part of the mercury used in filling the vessel†.

In the summer of 1781, Mr Cavendish, who had been informed of the experiments of Priestley and Warltire, set fire to 500,000 grain measures of hydrogen gas, mixed with about 2½ times that quantity of common air. By this process he obtained 135 grains of pure water. He also exploded 19,500 grain measures of oxygen gas with 37,000 of hydrogen gas, and obtained 30 grains of water, containing in it a little nitric acid. From these experiments he concluded that water is a compound.—Mr Cavendish must therefore be considered as the real discoverer of the composition of water. He was the first who ascertained that water is produced by firing oxygen and hydrogen gas, and the first who drew the proper conclusion from that fact. Mr Watt, indeed, had also drawn the proper conclusion from the experiments of Dr Priestley and Mr Warltire, and had even performed a number of experiments himself to ascertain the fact, before Mr Cavendish had communicated his; but he had been deterred from publishing his theory by some experiments of Dr

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* Priestley, v. 395.

† *Phil. Trans.* lxxiv. 332.

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Priestley, which appeared contrary to it *. He has therefore a claim to the merit of the discovery; a claim, however, which does not affect Mr Cavendish, who knew nothing of the theory and experiments of that ingenious philosopher.

Meanwhile, in the winter 1781-2, Mr Lavoisier, who had suspected that when oxygen and hydrogen gas are exploded, sulphuric or sulphurous acid is produced, made an experiment in order to ascertain the fact, at which Mr Gingembre assisted. They filled a bottle, capable of holding six pints (French), with hydrogen gas, to which they set fire, and then corked the bottle, after pouring into it 2 ounces (French) of lime water. Through the cork there passed a copper tube, by means of which a stream of oxygen gas was introduced to support the flame. Though this experiment was repeated three times, and instead of lime water a weak solution of alkali and pure water were substituted, they could not observe any product whatever †. This result astonished Mr Lavoisier exceedingly: he resolved, therefore, to repeat the experiment on a larger scale, and if possible with more accuracy. By means of pipes furnished with stop-cocks, he put it in his power to supply both gases as they should be wanted, that he might be enabled to continue the burning as long as he thought proper.

The experiment was made by Lavoisier and La Place on the 24th of June 1783, in the presence of Messrs le Roi, Vandermonde, several other academicians, and Sir Charles Blagden, who informed them that Mr Ca-

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* *Phil. Trans.* lxxv. 330.

† *Mem. Par.* 1781, p. 470.

vendish had already performed it, and that he had obtained water*. They continued the inflammation till all their stock of gases was wasted, and obtained about 295 grains of water, which, after the most rigid examination, appeared to be perfectly pure. From this experiment Lavoisier concluded, that water is composed of oxygen and hydrogen. Mr Monge soon after performed the same experiment, and obtained a similar result: and it was repeated again by Lavoisier and Meusnier on a scale sufficiently large to put the fact beyond doubt†.

Proofs.

The proof that water is a compound of oxygen and hydrogen is, that when these two gases, mixed in proper proportions, are fired, they almost wholly disappear, and there is found in their place a quantity of pure water, as nearly equal to them in weight as can be expected in experiments of that delicate nature. The hydrogen gas is made to pass slowly from the glass jar in which it is contained, by means of a tube furnished with a stop-cock into a glass globe filled with oxygen gas. It is set on fire at the extremity of the tube, either by means of electricity or by a little phosphorus, and it continues to burn slowly till the whole of it is consumed. New portions of oxygen gas are introduced occasionally from another glass jar, by means of a tube furnished with a stop-cock. The water, as it is formed, is condensed in the glass globe. A great number of precautions are necessary to ensure the purity of the gases, and to measure their weight and the nature of the gas which remains after combustion. But for

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* *Mem. Par.* 1781, p. 472.

† Ibid. p. 474.

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these I refer to the account of the experiments themselves, which have been published by the French chemists in the Memoirs of the Academy of Sciences. The experiment on which the greatest dependence may be put was made in the year 1790 by Seguin, Fourcroy, and Vauquelin*. The weight of the gases employed in this experiment was,

	Grains Troy.
Hydrogen gas	862.178
Oxygen gas	5296.659
Azotic gas	151.402†
Total	6310.239

The water obtained amounted to 5943.798 grains troy, or 12 oz. 7 dwts. and 15.798 grains. It exhibited no mark of acidity, and appeared in every respect to be pure water. Its specific gravity was to that of distilled water as 18671 to 18670; or nearly as 1.000053 to 1.

The residuum of gas in the vessel after combustion amounted to 382.465 grains troy; and, on being examined, was found to consist of the following quantities of gases:

	Grains Troy.
Azotic gas	170.258
Carbonic acid gas	23.306
Oxygen gas	188.371
Hydrogen gas	0.530
Total	382.465

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* See *Ann. de Chim.* viii. 225.

† The presence of this gas was owing partly to the impurity of the oxygen gas employed; partly to the unavoidable admission of common air.

	Grains Troy.
Now the weight of the whole gases employed was . . .	6310.239
That of the water obtained, and of the residuum . .	6326.263
Or	16.024

grains more than had been employed. This approaches as near an equality as can be expected in experiments of this nature. The small surplus of azotic gas found after the combustion cannot be accounted for, unless we suppose some common air to have gained admission during the process.

As sufficient precautions had been taken to prevent the introduction of carbonic acid gas, the quantity found in the residuum must have been formed during the process. There must therefore have been a small quantity of carbon introduced. Now zinc often contains carbon, and hydrogen has the property of dissolving carbon; probably, then, the carbon was introduced in this manner. The carbonic acid found in the residuum amounted to 23.306 grains, which, according to Lavoisier's calculation, is composed of 8.958 grains of carbon and 14.348 grains of oxygen.

Subtracting these 8.958 grains of carbon, and the 0.530 of a grain of hydrogen, which remained in the vessel, from the total of hydrogen introduced, there will remain 852.690 grains for the hydrogen that disappeared.

Subtracting the 14.348 grains of oxygen which entered into the composition of the carbonic acid, and the residuum of oxygen, which amounted to 188.371 grains, the quantity of oxygen that disappeared will amount to 5093·940 grains.

	Grains Troy.
Hydrogen that disappeared	852.690
Oxygen	5093·940
Total . . .	5946.630
Quantity of water obtained	5943·798
Which is less than the gases consumed by	2.832

It is impossible to account for the exact coincidence of the water condensed with the weight of the gases consumed, unless we suppose it to be composed of these bodies.

Dr Priestley, however, who made a great many experiments on this subject, drew from them a very different conclusion; and thought he had proved, that during the combustion the two gases combine, and that the combination is nitric acid. This theory was adopted, or rather it was suggested, by Mr Keir, who has supported it with a great deal of ingenuity*.

Let us examine these experiments of Dr Priestley†, and see whether they warrant the conclusions he has drawn from them. The gases were exploded in vessels of copper. He found that the quantity of water obtained was always *less* than that of the gases which he had used. He obtained also a considerable quantity of nitric acid. In the experiment made on the largest quantity of the gases, and from which he draws his

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* Keir's *Dictionary*, art. *Nitrous Acid.*

† *Phil. Trans.* 1788.

conclusions, the quantity of liquid obtained amounted to 442 grains. This liquid was examined by Mr Keir. It was of a green colour; 72 grains of brown oxide of copper were deposited in it, and it contained a solution of nitrat of copper (copper combined with nitric acid). Mr Keir analysed this liquor: It consisted of pure water and nitrat of copper: and Mr Keir concluded that the nitric acid formed amounted to $\frac{1}{20}$ of the oxygen gas employed. Here then a quantity of oxygen and hydrogen gas has disappeared: What has become of them? They have combined, says Dr Priestley, and formed nitric acid. This nitric acid is only $\frac{1}{20}$ of their weight. Dr Priestley supposes, however, that it contains the whole oxygen and hydrogen that existed in these gases, and that all the rest of the weight of these gases was owing to a quantity of water which they had held in solution. Oxygen gas, then (for we shall neglect the hydrogen, which Dr Priestley was not able to bring into view at all), is composed of one part of oxygen and 19 of water. Where is the proof of this? Dr Priestley informs us, that he ascertained by experiment that half the weight of carbonic acid gas was pure water. Supposing the experiment accurate, surely it cannot be concluded from it that oxygen gas consists of $\frac{19}{20}$ parts, or almost wholly of water. It is impossible, therefore, from Dr Priestley's experiments, allowing his ingenious suppositions and conjectures their utmost force, to account for the disappearing of the two gases, or the appearance of the water, without admitting that this liquid is actually composed of oxygen and hydrogen. If we add to this, that oxygen gas can scarcely be procured absolutely free from some admixture of azote, and that his oxygen was always obtained either from red oxide of lead, or from black oxide of manganese, or red oxide of mercury, all of which substances yield a considerable proportion of azote; if we add, that it has been proved beyond the possibility of doubt, and to Dr Priestley's own satisfaction, that nitric acid is composed of oxygen and azote—we shall find it no difficult matter to explain the origin of that acid in Dr Priestley's experiments: and if we recollect that in Seguin's experiment, upon a much larger scale than Dr Priestley's, no nitric acid at all was formed, it will be impossible for us to believe that the compound formed by oxygen and hydrogen is nitric acid. Thus Dr Priestley's experiments rather confirm than destroy the theory of the composition of water. We obtain from them, however, one curious piece of information, that the presence of copper increases the quantity of nitric acid formed.

The proof for the composition of water, derived from the combustion of hydrogen gas, is rendered still stronger by reversing the experiment. When electric explosions are made to pass through water, part of it is decomposed and converted into oxygen gas and hydrogen gas. Messrs Van Troostwyck and Dieman, assisted by Mr Cuthbertson, filled a small glass tube, $\frac{1}{8}$ of an inch in diameter and 12 inches long, with distilled water. One end of this tube was sealed hermetically; but at the same time a small gold wire had been passed thro' it. Another wire passed through the open end of the tube, and could be fixed at greater or smaller distances from the first wire. By means of these wires, they made a great number of electrical explosions pass thro' the water. Bubbles of air appeared at every explosion, and collected at the top of the tube. When electric sparks were passed through this air, it exploded and disappeared almost completely. It must therefore have consisted of a mixture of oxygen and hydrogen gas, and this gas must have been formed by the decomposition of the water; for they had taken care to deprive the water before-hand of all its air, and they used every precaution to prevent the access of atmospherical air; and, besides, the quantity of gas produced did not diminish, but rather increase, by continuing to operate a number of times upon the same water, which could not have been the case had it been merely air dissolved in water: nor would atmospherical air have exploded and left only a very small residuum, not more than $\frac{1}{80}$ part. They had taken care also to prove that the electric spark did not contribute to form hydrogen gas; for on passing it through sulphuric and nitric acids, the product was not hydrogen, but oxygen gas*.

These experiments have been since repeated by Dr Pearson, assisted by Mr Cuthbertson. He produced, by means of electricity, quantities of gas from water, amounting to 56.5488 cubes of $\frac{1}{10}$ of an inch each; on nitrous gas being added to which, it suffered a diminution of bulk, and nitrous acid appeared to have been formed. It must therefore have contained oxygen gas. When oxygen gas was added to the remainder, and an electric spark passed through it, a diminution took place precisely as when oxygen and hydrogen gas are mixed: It must therefore have contained hydrogen. When an electric spark was passed through the gas thus produ-

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* *Jour. de Phys.* xxxv. 369.

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ced from water, the gas disappeared, being no doubt converted into water *.

Such are the proofs by which the component parts of water have been ascertained. If we consider them attentively, and compare them with a vast number of other chemical phenomena, all of which tend to confirm and establish them, we must allow, I think, that scarcely any physical fact whatever can be produced, which is supported by more complete evidence. There are indeed some galvanic phenomena which scarcely seem compatible with it; but the nature of this singular power is still too imperfectly understood to warrant even a conjecture concerning it.

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* Nicholson's *Journal*, i. 242.

SECT. III.

OF THE OXIDES OF AZOTE.

We have now only to consider the compounds formed by the combination of azote and oxygen; for the combinations of muriatic acid and oxygen have been always considered as acids. Azote and oxygen form two different oxides, both of which were discovered by Dr Priestley. They can only be exhibited in the state of a gas: Hence the first of them has been called *nitrous oxide gas*; the second, *nitric oxide gas*.

I. Nitrous Oxide Gas.

History.

Nitrous oxide gas was discovered by Dr Priestley about the year 1776, and called by him *dephlogisticated nitrous gas*. The associated Dutch chemists examined it in 1793, and demonstrated it to be a compound of azote and oxygen *. But for a full investigation of its properties, we are indebted to Mr Davy, who published an excellent dissertation on it in the year 1800. He gave it the name of *nitrous oxide* †.

Preparation.

1. It may be procured by the following process: Take any quantity of *nitrat of ammonia* (a salt composed

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* *Jour. de Phys.* xlii. 323.

† *Researches, chiefly concerning nitrous oxide.*

of nitric acid and ammonia) in crystals, and expose it in a retort, by means of a lamp, to a heat not under 340°, nor above 500°. It melts rapidly, and is decomposed, emitting a great quantity of gas, which issues from the mouth of the retort, and may be received in glass jars in the usual manner. The gas which comes over is *nitrous oxide*. This process was first pointed out by Berthollet; but it was much simplified by Mr Davy *.

Properties.

2. Nitrous oxide gas, thus obtained, has all the mechanical properties of air: but it is much heavier than air; its specific gravity, according to Davy, being 0.00197. It is to common air nearly as 5 to 3 †. One hundred cubic inches of it weigh 50.20 grains.

It is capable of supporting combustion even better than common air; almost as well indeed as oxygen gas. A candle burns in it with a brilliant flame and a crackling noise. No combustible, however, burns in it, unless it be previously brought to a state of ignition.

Dr Priestley and the Dutch chemists had concluded that it cannot be respired; but they did not examine it in a state of purity ‡. Mr Davy ascertained that it may be breathed for several minutes without any bad effects. The feelings produced by breathing it bear a strong resemblance to intoxication; but they are not followed by that langour and debility which is a con-

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* Mr Proust has remarked, very justly, that the gas which comes over at the beginning of the process differs a little from nitrous oxide, and yet it is not *nitrous gas*.

† Davy's *Researches*, p. 94.

‡ Dr Priestley indeed found, in one instance, that a mouse breathed it five minutes without uneasiness. In this experiment he seems to have obtained it nearly pure.—Priestley, ii. 84.

stant attendant of intoxication *. It cannot be breathed longer than about four minutes, without the loss of voluntary motion altogether. When animals are confined in it, they give no signs of uneasiness for some moments ; but they soon become restless, and, if not removed in a very few minutes, die altogether. Hence we see that, though this gas be respirable, it is much less so than common air or oxygen gas †.

Action of water.

3. This gaseous oxide is absorbed pretty rapidly by water, as Dr Priestley ascertained, especially when agitated. Water absorbs 0.54 parts of its bulk of this gas, or 0.27 of its weight. It acquires a sweetish taste ; but its other properties do not differ perceptibly from common water. The whole of the gas is expelled unaltered by boiling the water ‡. When this gas combines

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[*] Mr Davy describes the effects it had upon him as follows : "Having previously closed my nostrils and exhausted my lungs, I breathed four quarts of nitrous oxide from and into a silk bag. The first feelings were similar to those produced in the last experiment (giddiness) ; but in less than half a minute, the respiration being continued, they diminished gradually, and were succeeded by a sensation analogous to gentle pressure on all the muscles, attended by an highly pleasurable thrilling, particularly in the chest and the extremities. The objects around me became dazzling, and my hearing more acute. Towards the last inspirations, the thrilling increased, the sense of muscular power became greater, and at last an irresistible propensity to action was indulged in ; I recollect but indistinctly what followed ; I know that my motions were various and violent.

"These effects were soon ceased after respiration. In ten minutes I had recovered my natural state of mind. The thrilling in the extremities continued longer than the other sensations" Davy's *Researches*, p. 457. The gas has been breathed by a very great number of persons, and almost every one has observed the same things. On some few, indeed, it has no effect whatever, and on others the effects are always painful.

[†] Davy's *Researches*, p. 94.

[‡] Priestley, ii. 81.

with the water, it expels the common air which was formerly dissolved in the water. Hence the residuum of common air, which always appears when this gaseous oxide is exposed to a sufficient quantity of water *.

4. This gas is not altered by exposure to light, nor to any heat below ignition; but when made to pass through a red hot porcelain tube, or when electric sparks are made to traverse this gas, it is decomposed, and converted into *nitric acid* and *common air* †.

5. There is no action between this gas and air, or oxygen gas.

Of the simple combustibles.

6. Sulphur, at the common temperature of the air, is not altered by this gas. If it be introduced into it while burning with a blue flame, it is immediately extinguished; but if introduced while burning with a white flame, it continues to burn for some time with great brilliancy, and with a fine red flame. The products are sulphuric acid and azote. When about the half of the nitrous oxide is decomposed, the sulphur is extinguished ‡.

Phosphorus may be melted and sublimed in this gas without alteration; it may be even touched with a red hot wire without undergoing combustion; but when touched with a wire heated to whiteness, it burns, or rather detonates, with prodigious violence. The products are azotic gas, phosphoric acid, and nitric acid: a part of the oxide remains undecomposed §.

Charcoal, confined in this gaseous oxide, may be kindled by means of a burning-glass. It continues to burn

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* Davy, p. 89.

† Priestley, ii. 91. and Davy, ibid. p. 279.

‡ Davy, Ibid. p. 303.

§ Ibid.

with great brilliancy, till about the half of the gas is consumed. The products are carbonic acid gas and azotic gas *.

Hydrogen gas and nitrous oxide gas detonate violently with a red flame, when a strong red heat is applied, or when the electric spark is made to pass through the mixture. When the proportion of hydrogen is nearly equal to that of the oxide, the products are water and azote; when the proportion of hydrogen is small, nitric acid is also formed †.

Sulphureted, phosphureted and carbureted hydrogen gas likewise burn when mixed with nitrous oxide, and exposed to a strong red heat. The products differ, according to the proportions of the gases mixed.

7. Neither azote nor muriatic acid appear to have any marked action on this gaseous oxide.

Of the metals.

8. On some of the metals it acts with great energy at high temperatures. Thus iron wire burns in it with the same brilliancy as in oxygen gas, though the combustion lasts but a very short time. The iron is converted into black oxide; part of the nitrous oxide is decomposed, its azote is evolved, while its oxygen combines with the iron ‡. Zinc also may be oxydized in this gas §. Its effect upon the other metals has not been tried.

Azotites.

9. Oxide of azote is capable of combining with alkalies, and forming salts of a very peculiar nature; for the discovery of which we are indebted to the sagacity of

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* Davy, 311.

† Priestley, ii. 83. and Davy, p. 286.

‡ Ibid. ii. 86.

§ Davy, p. 317.

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Mr Davy. No combination takes place when the alkalies are exposed to nitrous oxide in the gaseous state. But if it come into contact with them at the instant of its formation, it combines with them very readily. As these combinations have not yet received a name, we may call them *azotites* till some better appellation be thought of *.

Azotite of potass may be formed by the following process: Nitrous gas (a substance which will be described immediately), by confining in it crystallized sulphite of potass †, is gradually deprived of a portion of its oxygen, and converted into nitrous oxide. If very finely pulverised sulphite of potass, mixed with potass, be exposed for a great length of time in a sufficient quantity of nitrous gas, it is changed almost completely into sulphat of potass, while the oxide of azote, as it is evolved, combines with the pure potass. Consequently the salt is converted into a mixture of sulphat of potass and azotite of potass. The sulphat may be separated by solution, evaporation, and crystallization in a low temperature.

Azotite of potass is obtained in irregular crystals. It is composed of about three parts of alkali and one part of nitrous oxide. It is soluble in water. Its taste is caustic, and it has a peculiar pungency. It converts

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* Mr Davy has proposed to call them *nitroxis*; but this name is exceptionable, not only because it is contrary to the idiom of the English language, but because it is inconsistent with the rules laid down for forming chemical terms.

† Potass combined with sulphurous acid. This salt has a strong affinity for oxygen. It absorbs it from nitrous gas, and is converted into *sulphat of potass*. Hence the change of nitrous gas to nitrous oxide.

vegetable blues into green. Pulverized charcoal, mixed with it, and inflamed, burns with slight scintillations. When projected into zinc in fusion, a slight inflammation takes place. All acids, even carbonic, seem capable of expelling the nitrous oxide from the potass *. The other properties of this salt have not been examined.

Azotite of soda may be formed in the same manner, and seems to agree nearly in its properties with azotite of potass. The nitrous oxide is disengaged from it by a heat of between 400° and 500°. Its taſte is more acrid than that of azotite of potass, and it seems to contain less oxide of azote †.

Mr Davy did not succeed in combining nitrous oxide with ammonia and earths; but he has rendered it probable that these azotites may be formed.

Composition.

10. From the history of the properties of nitrous oxide gas just detailed, it is obvious that it is a supporter of combustion, and therefore that it contains oxygen in the same state as it exists in other supporters. That its other component part is azote, cannot be doubted, if we consider that either azote or nitric acid is constantly evolved when nitrous oxide is decomposed. The experiments of Mr Davy leave no doubt that these two substances are its only constituents. This philosopher found that 39 measures of nitrous oxide gas are capable of saturating 40 measures of hydrogen, and that after combustion the residue consists of 41 measures of azotic gas. But 40 measures of hydrogen were found to require

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* Davy, p. 262.

† Ibid. p. 268.

20.8 measures of oxygen *. From this it follows, that if the component parts of nitrous oxide were merely mixed together, the bulk of them would occupy a third more room than when combined. For 40 measures of nitrous oxide would be resolved into 20.8 measures of oxygen gas and 40 measures of azotic gas †. But 20.8 cubic inches of oxygen gas weigh about 7 grains, and 40 of azotic gas about 12 grains. Hence it follows, that nitrous oxide is composed of 7 parts by weight of oxygen, and 12 of azote, or nearly

63	Azote,
37	Oxygen,
100	

This statement coincides very nearly with the specific gravity of nitrous oxide. Thirty-nine cubic inches of nitrous gas, if the composition here given were precise, ought to weigh 19 grains. In reality they weigh 19.69 grains. The component parts of this gas, as obtained by the Dutch chemists, differ very little from the result of Mr Davy's experiments.

Much is still wanting to render the history of this singular substance complete. Mr Davy has laid open a very interesting field of investigation, which promises, if pursued far enough, to throw much light upon the nature of combustion; an operation more intimately connected with azote and its compounds than is at present supposed.

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* Davy, p. 291.

† I omit one measure, because the gases were not absolutely pure.

II. NITRIC OXIDE.

History.

NITRIC oxide, usually denominated *nitrous gas*, was obtained accidentally by Dr Hales; but its nature and properties were investigated by Priestley, in one of the first excursions made by that illustrious philosopher into the then unbeaten tracts of pneumatic chemistry. As the phenomena exhibited by this oxide are intimately connected with the most important investigations in chemistry, its properties were examined with great care, and occupied the attention of almost every chemist of eminence.

Preparation.

1. It may be obtained by the following process: Put copper or mercury into a glass retort, and pour over it somewhat diluted nitric acid. The metal is rapidly dissolved with a strong effervescence, and a great quantity of gas issues from the mouth of the retort, which may be received in glass jars. This gas is *nitrous gas*.

Properties.

2. When pure it is invisible like common air, of which it possesses the mechanical properties. Its specific gravity, according to Kirwan, is 0.001458*; according to Davy, 0.001343†. This last is most to be depended on, because Mr Davy's experiment was susceptible of greater precision than that of Mr Kirwan. Nitrous gas, then, is to common air nearly as 34 to 31. One hundred cubic inches of it weigh 34.26.

Nitrous gas is exceedingly noxious to animals, producing instant suffocation whenever they attempt to breathe it.

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* *On Phlogiston*, p. 28.

† *Researches*, p. 6.

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Supports combustion.

3. The greater number of combustible bodies refuse to burn in it: A taper, for instance, is extinguished the moment it is plunged into nitrous gas; the same thing happens to sulphur, even though previously burning with a white flame. It is capable, however, of supporting the combustion of several bodies, as has been ascertained by the experiments of Priestley and Davy. When Homberg's pyrophorus * is introduced into nitrous gas, it takes fire spontaneously, just as it does in common air. Phosphorus, too, when introduced into this gas in a state of inflammation, burns with as much splendor as in oxygen gas †.

Action of air

4. When nitrous gas and common air are mixed together, the mixture instantly assumes a yellow colour, heat is evolved, and the bulk of the two gases diminishes considerably; slowly, if the experiment be made over mercury; but rapidly, if it be made over water. When the diminution has reached its maximum, the mixture becomes perfectly transparent. The yellow colour is owing to a quantity of nitrous acid which is formed, and the diminution of bulk to the gradual absorption and condensation of this acid. What remains after this absorption is only azotic gas. The cause of this remarkable phenomenon is obvious. The nitrous gas combines with the oxygen of the air, and forms nitrous acid, which is condensed; while the azote of the air remains behind in the form of a gas. Hence with equal quantities of nitrous gas and air the diminution of bulk is always proportional to the quantity of oxygen present

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* This substance will be described hereafter. The combustible part of it is charcoal and sulphur.

† Davy, p. 134.

in the air. Hence it informs us of the proportion of that substance in any particular air. The same phenomenon takes place when oxygen gas and nitrous gas are mixed; but the condensation is much more considerable. Indeed it would be complete, provided the two gases were perfectly pure, and mixed in the proper proportions.

And oxygen.

When electric sparks are made to pass through nitrous gas, it is decomposed and converted into nitrous acid and azotic gas*.

Absorbed by water.

5. Nitrous gas is readily absorbed by water. From an experiment of Mr Davy, it appears that 100 cubic inches of water at the common temperature, and previously freed from air, absorb 11.8 cubic inches of nitrous gas, or nearly one-tenth, as Dr Priestley had ascertained. This solution has no particular taste, and does not redden blue vegetable colours. The gas is expelled again by boiling the water†; it separates likewise when the water is frozen‡.

Action of combustibles,

6. Nitrous gas is decomposed by phosphorus and charcoal at a very high temperature, and probably also by sulphur. These substances are converted into acids by combining with the oxygen of the gas while its azote is evolved.

Hydrogen gas mixed with it acquires the property of burning with a green flame. A mixture of these two gases does not take fire when electric sparks are made to pass through it; but, according to Fourcroy, it de-

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* Priestley, ii. 22

† Davy, p. 143.

‡ Priestly, i. 407.

tonates when made to pass through a red hot porcelain tube ; water is formed, and azotic gas evolved *.

Incombustibles,

7. Nitrous gas has no action whatever on azotic gas, even when assisted by heat. Neither does it act on muriatic acid.

And metals.

8. Several of the metals have the property of decomposing it, especially when assisted by heat. This is the case particularly with iron. Dr Priestley confined a portion of nitrous gas for some time in contact with a number of iron nails ; the gas was converted into oxide of azote, in consequence, doubtless, of the iron abstracting part of its oxygen †. It was in this manner that nitrous oxide was discovered by that philosopher. When the iron is heated to redness by means of a burning-glass, the decomposition is complete, the whole of the oxygen is abstracted from the nitrous gas, and only azotic gas remains behind ‡.

Absorbed by sulphat of iron.

9. Dr Priestley ascertained that nitrous gas is absorbed by the green sulphat of iron ; a property which is employed successfully to ascertain its purity. All that is necessary is, to expose a given portion of nitrous gas in a close vessel to the action of the green sulphat ; the quantity of gas which remains unabsorbed gives the proportion of foreign bodies with which it is mixed. Mr Davy has proved, that all the salts containing the green oxide of iron possess the same property, and that they all absorb nitrous gas unaltered. The greatest part of it may even be expelled again by the application of

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* Fourcroy, ii. 91.

† Priestley, ii. 54.

‡ Ibid. p. 38.

heat. Several other metallic salts possess the same properties *.

Converted into nitrous oxide.

10. The following bodies have the property of converting nitric oxide into nitrous oxide:

Alkaline sulphites,
Hydrogenated sulphurets,
Muriat of tin,
Sulphureted hydrogen gas,
Iron or zinc filings moistened with water.

To produce this effect, nothing more is necessary than to put these substances into jars filled with nitric oxide gas, and allow them to remain for a week or two. The substances gradually combine with a portion of oxygen, and are converted into oxides or salts †.

11. Nitrous gas is absorbed by alkaline solutions; but it does not appear from the experiments hitherto made, that it is capable, like oxide of azote, of combining with alkalies and earths, and forming salts.

Composition.

12. The conversion of nitric oxide gas into nitric acid, by combining it with oxygen, is a demonstration that it contains azote as a constituent part; and the property which several bodies have of absorbing oxygen from it, and converting it into nitrous oxide gas, is a demonstration that oxygen is the only other ingredient which it contains. But it is by no means easy to ascertain

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* Davy, p. 179.

† Priestley and Davy, *passim*.—During the action of the two last bodies on nitrous gas, ammonia is likewise formed.

the proportion of these two constituents. Mr Lavoisier, from a set of experiments made at an early period, and in a manner not susceptible of much accuracy, estimated their proportions at about 68 oxygen and 32 azote. But this estimate is irreconcileable with the experiments of other philosophers. The proportions obtained by Mr Davy deserve much more confidence, as his method was susceptible of greater accuracy. By means of a burning glass he exposed to the action of the sun's rays a small portion of prepared charcoal, placed in a measured quantity of nitric oxide gas standing over mercury. The weight of the charcoal did not exceed a quarter of a grain, and the gas amounted to 16 very small measures. After the process was finished, the bulk of the gas was increased about $\frac{1}{4}$ of a measure. The whole of the nitric oxide was decomposed. Potass ley rapidly absorbed the whole of the gas except eight measures, which were pure azote. But the gas originally was found by experiment to contain 0.6 of a measure of azote. Therefore 15.4 measures of nitric oxide, when decomposed by charcoal, are converted into 16.15 measures; 7.4 of which are azote, and 8.75 carbonic acid. But 15.4 measures of nitric oxide weigh 5.2 grains, and 7.4 measures of azote weigh 2.2 grains. Hence it follows that 5.2 grains of nitric oxide contain 2.2 of azote; the remaining 3 grains must be oxygen. This gives us nitric oxide composed of 2.2 azote and 3 oxygen, or of 57.7 oxygen and 42.3 of azote. The carbonic acid produced weighed 4.1 grains, and contained 1.15 grains of charcoal combined with 2.95 grains of oxygen, which it had absorbed from the nitric oxide. This gives us 5.2 grains of nitric oxide, composed of

2.95 oxygen and 2.25 azote; or 100 parts contain 57 oxygen and 43 azote, which differs very little from the last estimate *. We may consider the last numbers as the nearest approximations to the composition of nitric oxide.

The proportion of oxygen contained in the compounds of azote, according to these results, may therefore be stated thus:

Azote.	Oxygen.	
100	58.7	Nitrous oxide
100	132.5	Nitric oxide
100	239.9	Nitric acid

Hence it follows that

$$\overset{\text{Azote.}}{1.00} + \overset{\text{Oxygen.}}{0.587} = \overset{\text{Nitrous oxide.}}{1.587}$$

$$1.587 + \overset{\text{Oxygen.}}{0.738} = \overset{\text{Nitric oxide.}}{2.325}$$

$$2.325 + \overset{\text{Oxygen.}}{1.074} = \overset{\text{Nitric acid.}}{3.399}$$

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* Davy, p. 129.

Oxides divisible into three sets.

Such are the properties of the oxides formed by the combination of the different combustible and incombustible bases with oxygen. Though they have been all classed together by chemists from the single circumstance of their containing oxygen, they by no means resemble each other in their properties, and ought, in strict propriety, to be divided into three sets, each of which forms a very distinct class of substances. The first class comprehends those oxides which are still combustible, and which may therefore be called *combustible oxides*. The second class consists of oxides which have been formed by combustion, and which of course are incombustible. They may be denominated *oxide products*. The third set consists of combinations of oxygen with combustibles. They are neither combustible, nor can they be formed by combustion; but they are all capable of supporting combustion. They may be called *oxide supporters*. It must be obvious at once, that the oxygen which constitutes the characteristic constituent must be in a very different state in each of these classes.

1. The *combustible* oxides include only those which have carbon for a base: but the oxides of sulphur and phosphorus belong also to the same class.

2. The class of oxide products contains only one substance, water, the base of which is hydrogen. But many of the metallic oxides belong obviously to this class.

3. The class of oxide supporters contains only the oxides whose base is azote; but oxy-muriatic acid, and several of the metallic oxides, ought, in strict propriety, to be referred to this class.

END OF THE FIRST VOLUME.

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Plate I. CHEMISTRY *End of Vol. I.*